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Does money really grow on trees? A case study of the economic and ecosystem outcomes of timber stand improvement in New Hampshire

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DOES MONEY REALLY GROW ON TREES? A CASE STUDY OF THE ECONOMIC AND ECOSYSTEM OUTCOMES OF TIMBER STAND IMPROVEMENT IN NEW HAMPSHIRE

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ABSTRACT

DOES MONEY REALLY GROW ON TREES? A CASE STUDY OF THE ECONOMIC AND ECOSYSTEM OUTCOMES OF TIMBER STAND IMPROVEMENT IN NEW HAMPSHIRE

By

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Timber stand improvement (TSI) is one silviculture method that landowners can apply to their forest to enhance timber quality as well as ecosystem services, such as deadwood in the form of standing deadwood, snags, and coarse woody debris (CWD). There are few studies on the economic effectiveness of TSI as a forest management practice. This research uses data collected on land owned by the Blue Hills Foundation, in Strafford, New Hampshire, to present a case study examining economic and ecosystem outcomes of TSI. Because interest rates and market prices are constantly fluctuating, we evaluated outcomes at various interest rates. We have built a model that landowners can use by inputting their own treatment costs, interest rates, and timber values to determine the financial performance of TSI treatment. The results of our study suggest that TSI can be an effective and cost-efficient forest management practice at low interest rates. TSI may also enhance standing deadwood, snags, and CWD, which provide important ecosystem services such as wildlife habitat and carbon storage ability. For this study, TSI increased the volume and number of pieces per acre of these forms of deadwood. We combined information from the deadwood analysis with that of the financial analysis to determine an implicit value of deadwood necessary for net present value to breakeven in our groups where net present value was negative based solely on the timber evaluation.

INTRODUCTION

New England forests are composed of a variety of forest types and tree species. The spruce-fir forest type is dominated by balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*). Northern hardwood forests contain American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*). Transition forest types contain softwood species, such as eastern white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*), and hardwoods such as northern red oak (*Quercus rubra*) (Foster 1995). Each of these forest types are present in New Hampshire, and each species contributes to the state's economy.

Forests provide multiple products and ecosystem services that affect economies and environmental quality. Timber may be sold for end uses such as furniture, construction materials, paper, and as an energy source. Trees, snags and coarse woody debris (CWD) provide a multitude of ecosystem services including food and habitat for a suite of native wildlife species. These forms of wood also store carbon dioxide for decades, reducing the impacts of climate change.

Timber stand improvement (TSI) is a broad class of silvicultural practices that improves future timber outcomes and provides ecological benefits. One objective of TSI is to reduce competition around chosen crop trees – those with the best potential for high quality in the future. Girdling is a TSI technique that involves cutting a ring around the sapwood at the base of a tree to kill it (Nyland et al. 2016). The girdled trees die in place, creating snags, and eventually fall, contributing to CWD.

There are many ecosystem services provided by living trees, dead trees, soil, leaf litter, plants and other forest components. These services generally do not have market values, so provision of these services is often not considered in economic decisions. To slow the effects of climate change and continue to provide a sustainable source of resources for human societies forests must be responsibility managed (Jenkins and Schaap 2018). By evaluating the additional benefits of snags and CWD, from a wildlife and carbon sequestration standpoint, a case may be made for why TSI treatment might still result in positive outcomes even if the practice does not ultimately improve timber value.

To better understand financial and ecological outcomes of TSI treatment, we examine the case of a series of TSI treatments conducted from 1989 to 2003 on a large private forest in Strafford, New Hampshire. The landowner, the Blue Hills Foundation, owns more than 7,000 acres that is primarily forested but contains small areas of farmland and various water features. When TSI activities were conducted, the foundation was interested in the financial gain from creating better quality timber, but today its objectives are multifaceted.

Thesis Organization

This thesis consists of two chapters describing our case study of TSI treatment in Strafford, New Hampshire. The current section is the Introduction. Chapter I and Chapter II are written independently as they are intended to be manuscripts for journal submissions. Chapter I focuses on the financial outcomes of TSI treatment based on timber quality and economic value of living trees. Chapter II focuses on ecological services from snags, standing deadwood and CWD, that may be enhanced by TSI treatment. The Conclusions section at the end of the thesis summarizes the results of Chapter I and Chapter II. It will also discuss the significance of our findings as they pertain to TSI as a forest management tool, project limitations and suggestions for future work.

CHAPTER 1

Introduction

New England forests are composed of a variety of forest types and tree species. The spruce-fir forest type is dominated by balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*). Northern hardwood forests contain American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*). Transition forest types contain softwood species, such as eastern white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*), and hardwoods such as northern red oak (*Quercus rubra*) (Foster 1995). Each of these forest types are present in New Hampshire, and each species contributes to the state's economy.

Forests provide numerous products and ecosystem services that affect economies and environmental quality. Timber may be sold for end uses such as furniture, construction materials, paper, and as an energy source. Trees, snags and coarse woody debris (CWD) provide a multitude of ecosystem services including food and habitat for a suite of native wildlife species (Homyack et al. 2011). These forms of wood also store carbon (Campbell et al. 2019).

New Hampshire is the second most forested state in the country with 84% of its land mass covered in forest. This makes forests an important resource for the state's economy. In 2013 the annual value of sales from forest products, such as those mentioned above, was estimated to be $1.4 billion. Forest-based recreation typically matches that yearly contribution to New Hampshire's economy (NEFA 2013). High-quality timber and forest-based recreational opportunities are especially important to the state's rural economy.

Eastern white pine is one of New Hampshire's greatest forest assets. Even though there are more individual trees of other species including red maple, eastern hemlock, and balsam fir, white pine accounts for the largest volume (2 billion cubic feet) of any species. White pine is also the most harvested species in the state – in 2016, about 27 million cubic feet were removed. For perspective, sugar maple was removed at the second highest rate at a little over 18 million cubic feet (Morin and Lombard 2017). Nearly all lumber mills in the state process white pine (UNH Extension 2020).

To achieve economic and ecosystem objectives, landowners apply silviculture treatments to support ecosystem functions as well as health and productivity of forests (Nyland et al. 2016). Management of forests held by families and small organizations is supported by public programs that encourage active treatment of the nearly 35% privately-owned forestlands across the United States. Public cost-share programs are often utilized by landowners to financially support the management activities they implement (Stoots et al. 2017). These programs provide incentives for landowners to conduct activities such as TSI on their forestlands.

A modest amount of research has been done on the effectiveness of cost-share programs. Most of these studies, however, are primarily focused on how cost-share programs motivate landowners to conduct forest management rather than the financial performance of the management activity. For example, Arbogast (2015) summarized incentive programs of each state for small landowners. Some states have incentive programs for TSI activities, but this study only provides results about how effective these programs are rather than the economic outcomes of the treatments. Similar studies have been conducted by Jacobson et al. (2009) and Stoots et al. (2017). Researchers suggest that those who seek not only timber value but also nontimber values from their forest are more likely to invest in forest management with the support of cost-share programs (Hyberg and Holthausen 1989, Kilgore et al. 2015).

Timber stand improvement is a broad class of silvicultural practices that improves future timber outcomes and provides ecological benefits. One objective of TSI is to reduce competition around chosen crop trees – those with the best potential for high quality in the future. Girdling is a TSI technique that involves cutting a ring around the sapwood at the base of a tree to kill it (Nyland et al. 2016). The girdled trees die in place, creating snags, which eventually fall, contributing to CWD. The financial objective is to focus the productivity of the stand on the more economically valuable trees. For our case study, white pine was the targeted economically valuable species. Timber stand improvement is a strong choice for small forest landowners because treatment is low cost compared to other treatment methods, it is a short-term management practice and it can provide high returns (Anderson 1975).

Timber stand improvement is most successful when conducted at an appropriate age. If the stand is very young, it may be difficult to detect which trees should be favored as crop trees. In young stands, a target stand age of 20 years is suggested to help determine which trees should be chosen as crop trees and have greater success with TSI practices (Lancaster 1975). If the stand is too old, with many mature trees, the effects of treatment may have little or no impact on future timber quality.

There are some previous studies of TSI effectiveness. In 1935, Pearson examined the financial capabilities of TSI for the southwest portion of the United States. In his study, he was unable to obtain exact numbers for TSI input costs. In his analysis, he noted the fact that future treatment costs are unpredictable, so his cost values were imprecise. Therefore, he made conservative estimates of future cost per acre values based on available information from historic costs but did not consider how many times TSI would need to be repeated for young trees to grow to merchantable size. Using calculated changes in timber yield over time and his cost estimates, he ultimately concluded that TSI, at low interest rates and conducted on suitable stands, would return input costs (Pearson 1935).

Results of TSI five years after treatment were examined by Burell (1943) in the southern Appalachian Mountains on hardwood species. He found that the taller a crop tree was at the time of treatment, the less likely it would be overtaken by surrounding competition, which included the sprouts of cut or girdled trees. He also evaluated tree height and diameter growth five years prior to and five years after TSI. Height growth averaged almost 40% greater and diameter growth 54% greater during the five years after treatment compared to the five years before treatment (Burell 1943).

An appraisal study in the Ozark National Forest took place 15 years after a TSI treatment (Shoulders 1956). In this study, TSI activities were justified overall because understory basal area and stem quality improved due to TSI treatment. Shoulders determined that results could have been further enhanced had some large overstory trees been removed prior to the TSI treatment. In the hardwood sites the value per acre was under five dollars pre-treatment and rose to fifteen dollars per acre 15 years post-treatment. The pine sites, though initially poorer, also increased in value, though this gain was much smaller (less than one dollar) (Shoulders 1956). These numbers were based on observed values and did not consider the time value of money.

Similar results to the Burell (1943) study were obtained in a study conducted in the University of Kentucky's Robinson Forest where researchers Moriarty and McComb (1983) found that using TSI to release various species of suppressed trees in the canopy increased tree growth as well as stand density for up to 30 years after treatment.

Timber quality improvement via TSI was studied in the Bartlett Experimental Forest in the White Mountains of New Hampshire. Though this study focused on northern hardwood species, rather than white pine, the researchers were able to conclude that TSI activities applied to the remaining forest after a commercial harvest improved tree grade distribution 40 years later. Average tree grade increased by roughly one-half grade after TSI activities were completed. Though that is only a small quality value change it equates to a noticeable change in monetary value in the harvested timber (Sendak et al. 2000).

Though some previous research has examined TSI in several parts of the United States, the only New England study focused on hardwood stands rather than white pine dominated stands. Moreover, other previous TSI studies are quite dated, do not focus on white pine dominated forests and focus more on biometric outcomes rather than timber quality and value outcomes. Additionally, timber prices and treatment costs have changed a great deal since these studies were completed.

To better understand financial outcomes, we examine the case of a series of TSI treatments conducted from 1989 to 2003 on a large private forest in Strafford, New Hampshire. The landowner, the Blue Hills Foundation (BHF), owns more than 7,000 acres that are primarily forested but contains small areas of farmland and various water features. When TSI activities were conducted, the foundation was interested in the financial gain from creating better quality timber, but today its objectives are multifaceted and include providing additional wildlife resources. The foundation’s records indicate the types of TSI activities that took place, where they occurred and how much the work cost, including public cost-share payments from the Natural Resources Conservation Service (NRCS). No biometric data were collected on the stands from the times of treatment.

Landowner decision-making would benefit from access to information that can help them determine whether TSI is worthwhile for their forest. They would also benefit from having a tool that they can utilize to assess the economic outcomes of TSI if they have already conducted treatment on their forests or plan to do so. A model that evaluates financial components can provide them with this information.

In this study, we used the foundation's financial data and our field-collected data to test a model that can be used to evaluate the financial outcomes of TSI activities. This case study will help bridge knowledge gaps and provide a framework by which other forest owners can make decisions about the applicability of TSI practices on their forests. Our objectives for this project are to determine if the BHF had any positive net present value as of 2019 for their TSI treatments due to increased timber quality and quantity and to create a decision tool that landowners can utilize to evaluate outcomes to their own forest.

Methods

Model Concept

Markets are always changing, and interest rate and price fluctuations may not always be predictable, but it is important for landowners to be informed about the possible outcomes of a forest management treatment prior to conducting similar activities on their own property. It is also important to have a means for landowners who have already conducted treatment to calculate the financial outcomes of their efforts. The objectives of this project are to evaluate the financial performance of a case study of a series of TSI treatments and to create an Excel spreadsheet model that forest landowners can utilize on their own to evaluate the economic outcomes of their TSI activities. The model is tested with data collected from a large forest property in New Hampshire as a case study to verify the approach to the analysis. The model determines if the investments in TSI treatments were financially sound for the landowners. The results can guide other landowners interested in using TSI for their forests about the possible outcomes of treatment. It can also be used by landowners who have conducted TSI activities in the past to summarize their financial outcomes.

The model employs a "with and without" analysis. This method compares the result of an investment to the outcome without the investment (Davis et al. 2001). For this project, data from TSI treated stands represent the "with" side, and the data from untreated stands that were left to grow naturally represent the "without" side. Over many years the forest will still see change and growth with or without forest treatment, but we want to be able to determine how much difference may be attributable to the treatment and if that difference is large enough to justify the costs of treatment. The "with and without" method allows us to ignore taxes and other costs which were the same for the treated and untreated stands. In addition, in this case study, there are no intermediate revenues for either treated or untreated stands.

Site Description

Research for this project was conducted on land owned by the Blue Hills Foundation in Strafford, New Hampshire, USA (Figure 1). All sample plots are located between 550 and 850 feet in elevation (USDA NRCS 2019). The dominant soil types include fine sandy loam, very rocky fine sandy loam and areas of loamy sand (UNH Extension 2019). The sampling area generally consists of rolling hills with some steep areas and special features including a large waterfall, portions of Big River, an old mica mine and small ponds. In the southern portion of the study area slopes mostly face northeast as they approach the center of the property. On the northern portion of the study area, slopes have a southwestern aspect as they approach the center of the property. The forest in the sampling area is dominated by conifers, most of which are eastern white pine with some eastern hemlock scattered throughout. In small portions of the sampling area, hardwood species dominate. Approximately 70 years ago, prior to the BHF's acquisition of the land, much of the sampling area had been commercially clearcut.

From 1989 to 2003, TSI activities were completed on 2,000 acres of the almost 8,000-acre land-holding. The TSI methods utilized most were girdling larger diameter (> 10in.) trees and cutting down smaller diameter trees to release crop trees. All trees that were cut or girdled were left on site rather than removed from the property. Some pruning was also completed, but the BHF's records are not adequate to locate those treatments and there was little evidence of pruning observed in the sampling area. In most locations the landowners were releasing eastern white pine crop trees, so smaller white pines or other less desired species were cut or girdled.

Consequently, the standing deadwood, snags and CWD left on site also served as an important wildlife habitat resource.

Model Formulation

To determine if treatments were financially justified, we calculate the net present value (NPV) of the differences between treated and untreated stands on a per acre basis. If the NPV is positive, the treatment is justified. The general form of the model is:

$$NPV = (V^T - V^U) - C(1+r)^t \qquad \text{(Equation 1)}$$

where V^T and V^U are the per acre end year values of living timber for a treated stand and an untreated stand, respectively. These values are a function of tree species, volume, product, and tree grade as well as applicable stumpage prices. C is the per acre treatment cost t years prior to the end of the analysis period, in our case 2019, compounded by the interest rate, r.

In addition to NPV we calculated the internal rate of return (IRR). IRR is the interest rate which makes NPV equal zero. Our NPV represents the net difference between treated and untreated stands minus the compounded TSI costs. Because V^T and V^U occur at the same point in time, if (V^T-V^U) is negative, the IRR is undefined because both terms in Equation 1 are negative. Volumes and values by species and product are calculated using NED-3, a USDA Forest Service software package for modeling forest stands, applicable to the northeastern United States (USDA 2019).

NED-3 and its predecessors have been used in many forestry studies, including those focused around TSI. The program provides current stand condition data and can be used to predict future conditions. The underlying model of NED-3, the Northeast Variant of the Forest

Vegetation Simulator, has been used in other New England studies (Kenefic et al. 2014, Maguire et al. 2005, Gunn et al. 2014).

Stumpage prices used to value standing timber were obtained from the New Hampshire Department of Revenue Administration's Average Stumpage Value List for the southern region in 2019 (NHDRA 2019). Landowner costs for TSI activities are also required to determine NPV and IRR. We used the dollar per acre ($/ac.) value of TSI work for each year that TSI took place, which were obtained from records provided to us by the BHF. The sensitivity of results to interest rate changes were examined using historic interest rates over the time period that TSI activities took place. The details for generating the data for the timber volumes and values, TSI costs, and interest rates are described below.

Biometric Data Collection

Biometric data on treated and untreated stands were collected from May to August 2019. Hand-drawn maps provided by the landowner were digitized in ArcGIS, and ArcGIS was used to map transects within TSI-treated areas. On average, four chains (264 feet) were maintained between plots within and between each transect. Before sampling each plot, a visual inspection of the area was completed to confirm that the plot was within a TSI area, as evidenced by cut and girdled trees. Because treatments were applied for management rather than experimental purposes, we do not have true experimental control plots. Instead, untreated plots were located in untreated patches within treated stands and from proximate untreated stands with similar forest characteristics to create what will be referred to as our untreated plots.

We calculated the coefficient of variation using data from our initial samples to determine the sampling intensity needed for a 90% probability of achieving a 10% error. We actually measured more plots than necessary to meet these standards: 97 TSI (treated) plots and 30 untreated plots (Figure 2).

Each fixed-radius plot was one-tenth of an acre (radius = 37.5ft.) (Figure 3). Within the plot boundary, all living trees greater than four inches in diameter at breast height (DBH) were measured and data on species, height, crown class, number of sawlogs, number of pulplogs and tree grade were recorded. DBH was measured with a diameter tape and height was measured with a TruePulse 200 laser hypsometer. Crown class was visually determined as either dominant, co-dominant, intermediate or suppressed using Bechtold (2003). Merchantable height was recorded as the number of sawlogs and pulplogs based on the number of 16-foot logs in the bole of the tree, to the nearest half log, using the hypsometer. Trees were graded on a scale from 1 to 4 using Brisbin and Sonderman (1971) for softwood species (Table 1) and Hanks (1975) for hardwood species (Table 2). A grade of four was given to softwood and hardwood trees that contained all pulpwood.

Data on volume, product and tree grade underpin the timber-related financial analysis of our model. Diameter measurements also provide us with the ability to evaluate species composition by basal area per acre.

Grouping the Data

The BHF conducted TSI from 1989 to 2003, a span of 15 years. With a large number of plots in the treated areas (97), it was logical to group the plots for a more finite look as to how TSI treatment has affected the forest. To create these groups, we conducted a cluster analysis using PC-ORD (McCune and Grace 2019). This analysis did not provide us with any clear distinctions among plots, so we subjectively grouped the plots into five groups based on the chronological years of treatment. We attempted to make the number of sample plots in each group as balanced as possible while maintaining chronological order (Table 3). Group 5 contains all untreated plots. We also examine all treated plots versus all untreated plots. Our analyses will evaluate results for all species as well as for only eastern white pine, the target species for the BHF's TSI work.

NED-3 Analysis

Living tree data were entered into NED-3 (USDA 2019) to provide total timber values by treatment groups as discussed above by combining volume, tree grade, and stumpage prices per unit of volume. Current (2019) stumpage prices came from the New Hampshire Department of Revenue Administration's (NHDRA) Average Stumpage Value List for southern region log prices in 2019 for each species sampled. Grade 1 sawlogs were valued using the high unit price in dollars per thousands of board feet ($/MBF) listed by DRA for that species, Grade 3 sawlogs were valued using the DRA low value ($/MBF), and Grade 2 sawlogs were valued using the average ($/MBF) based on Grade 1 and 3 pricing. Grade 4 logs, which contain only pulpwood, were assigned the DRA dollar per cord ($/cord) value.

NED-3 also provided important biometric data including total basal area ($ft.^2/ac.$), basal area by species ($ft.^2/ac.$), total volume ($ft.^3/ac.$), volume by species ($ft.^3/ac.$), volume by forest product ($ft.^3/ac.$), and trees per acre. These data are used to explain differences or similarities in total timber values among our five groups and between our treated versus untreated plots. Basal area is used to analyze species composition.

Multiple chi-square tests were conducted as an additional method of understanding differences in timber values of the trees in the treated and untreated plots, as well as for values of the dominant species, eastern white pine. A chi-square test was conducted to determine if there was any statistical difference in the sawlog grade distribution of white pine trees among each of our five groups. A second chi-square test was done for white pine sawlog grade distribution in all treated versus all untreated plots. For these tests we only considered Grades 1, 2 and 3 because Grade 4 logs are pulpwood only and contribute little value to the stand. Both tests were done at the 0.05 significance level. An additional pair of chi-squared tests were done for all species in the five groups and all species in treated versus untreated plots.

As mentioned above, the analysis also requires financial data. For the case of the BHF, we wanted our analysis to include multiple scenarios to depict varying outcomes they could have encountered based on how interest rates have fluctuated between 1989 and 2019. The model is designed to analyze revenues based on any interest rate value that the user provides. Three interest rate values were used for our study: 2% (low), 4% (medium), and 6% (high). We chose 4% as our base interest rate and used that to set the higher and lower rates. These values are based on historical interest rate values that existed in the U.S. throughout the period between first treatment (1989) and time of the study (2019) from the Board of Governors of the Federal Reserve System (2019). Because taxes and other management costs are the same for treated and untreated plots, they are ignored in the "with and without" analysis. Additionally, there were no intermediate revenues to be tracked. All dollar amounts and interest rates are expressed in nominal terms.

From their financial records, the BHF provided us with the dollar per acre values that they spent each year on TSI treatments. They also gave us information about how much they received in cost-sharing for each year. These values are inputted into our model to calculate the NPV of the difference between Groups 1-4 versus Group 5 and between all treated stands versus all untreated stands at each of the three specified interest rates. Though cost-share contributions fluctuated from year to year, our financial performance results are based on total values (private and cost-share). We examine scenarios considering only white pine sawlogs and considering all sawlogs.

Results

Using field data and applicable stumpage prices from the New Hampshire DRA, we calculated biometric and economic values including basal area (ft.^{2}/ac.), sawtimber volume (board feet/ac.), and sawtimber value ($/ac.) as of summer 2019 when the data were collected. Results are presented in four sections: 1a) the five groups (four groups defined by treatment period and one group consisting of untreated plots) for eastern white pine, the landowner's target species for their TSI projects, 1b) the five groups for all tree species, 2a) all TSI plots versus all untreated plots for eastern white pine, and 2b) all TSI plots versus all untreated plots for all tree species. For each section, we examine the differences in total (BHF and cost-share) NPV (2019) between treated and untreated groups to determine if treatment had a positive or negative financial result at three selected interest rates (2%, 4% and 6%). The difference reflects the "with versus without" treatment of Equation 1 (Methods). The interest rates were used to compound TSI costs from the treatment year to 2019. The average cost of TSI work at the time of expenditure was lowest for Group 1 at approximately $58/acre. Each subsequent group's TSI cost increased until it averaged about $102/acre for Group 4. Average cost per acre of TSI work was $73 when all TSI plots are combined (Table 4). For each reporting section, we examine factors such as sawtimber volume, species composition, and tree grade distribution as a foundation for explaining differences in values. We also explored results of our internal rate of return (IRR) calculation, which provided us with the interest rate at which NPV equals zero.

1a) Group Results – Eastern White Pine

Focusing on eastern white pine, among the treated groups, Group 2 has the largest 2019 total timber value at just over $1,350/ac. Groups 1 and 3 are also valued over $1,000/ac. Group 4 is valued lowest at just under $425/ac. Group 5, which consists of all untreated plots, is valued at a little under $960/ac. (Table 5).

At an interest rate of 2%, the NPV, the difference between the treated groups and untreated group (Group 5), are positive for Group 1, Group 2 and Group 3. Group 3 has the highest net value at $285.74, and Group 4 has the lowest value, an approximate $425 lost. At 4% and 6% similar patterns emerged: Group 1 and Group 4 have negative values while Group 2 and Group 3 have NPV. The losses for Group 1 are much smaller than those of Group 4. At 4% and 6% interest, Group 2 continues to have the highest NPV (Table 6).

These results can be explained by differences in standing timber volumes, basal area of species composition and by differences in tree grade distribution. Group 2 contains the largest amount of white pine sawtimber volume at just over 10,500 board feet (bd. ft./ac.) (Table 7). By comparison, Group 4 contains just under 3,300 bd. ft../ac. of sawtimber. Group 1 and Group 3 are similar in sawtimber volume, around 9,000 bd. ft./ac.; Group 5 (containing all untreated plots) has under 8,000 bd. ft./ac.

Groups 1, Group 2 and Group 3 are predominantly comprised of white pine (at least 60% of species composition by basal area (ft.^{2}/ac.); but Group 4 is more diverse. Only 35% of species basal area is white pine in Group 4, and hardwoods dominate (36%). Group 5 species composition is also more evenly distributed, but again white pine still dominates with 38% of basal area (Table 8).

Chi-square tests were done for tree grade distribution of sawlogs to evaluate whether grade distribution contributes to differences in sawtimber values. Data for tree grades 1, 2, and 3 were included while grade 4 trees were omitted because such trees contain only pulpwood and contribute little to timber value. We found a significant difference in timber grade distribution of white pine sawlogs at the 0.05 significance level ($p = 0.000047$) (Table 9). For all groups, the vast majority of white pine trees were grade 3. Grade 1 was the least common tree grade for all groups with only one tree in Group 2 and 3 and zero trees in Group 1 and 4. Groups 2, 3 and 5 contained a higher proportion of grade 2 trees compared to Groups 1 and 4. Groups 1 and 4 contain a relatively higher amount of grade 3 trees than Groups 2, 3 and 5 (Table 10). Across all groups we can conclude that grade distribution is different.

Internal rates of return were calculated to determine the interest rate necessary for each group's difference from Group 5 to have a NPV equal to zero. Group 4 is not included due to its negative NPV value at all interest rates. Group 1 required a smaller interest rate (4%) than Groups 2 and 3 (7%) for NPV to equal zero for white pine (Table 11).

<u>1b) Group Results – All Tree Species</u>

For all tree species, among the treated groups, Group 2 has the largest 2019 total timber value at more than $1,885/ac. Group 3 is valued at more than $1,770/ac. Groups 1 and 4 were both above $1,200/ac., but Group 4 was valued lowest as it was for the white pine only assessment. Group 5 was valued higher than Groups 1 and 4 at more than $1,500/ac (Table 5).

At 2% interest, the NPV of the difference from Group 5 (untreated) are positive for Group 2 and Group 3. Group 2 had the highest difference at $274.65, and Group 4 had the lowest difference with a loss of $421.54. Group 1 also had a fairly significant loss of $316.64. At 4% and 6% the patterns are similar; at each interest rate, Group 2 had the highest difference, Group 3 remained positive, and Groups 1 and 4 contained negative NPV differences with Group 4 always having the most negative difference of all groups (Table 6).

Of our treated groups, Group 2 contained the largest volume of sawtimber when considering all tree species with more than 13,100 bd. ft./ac. Very close behind is Group 5, the group containing all untreated plots, with a total sawtimber volume slightly above 13,000 bd. ft./ac. Groups 1 and 3 both contained more than 11,000 bd. ft./ac., but Group 3 was slightly higher. Group 4 contained the lowest amount of sawtimber volume at just over 7,700 bd. ft./ac (Table 7).

Groups 1, 2, and 3 are predominantly comprised of white pine (at least 60% of species composition by basal area (ft.^{2}/ac.); but Group 4 is more diverse. Only 35% of species basal area is white pine in Group 4, but it is still the dominant species. Group 5 species composition is also more evenly distributed, but again, white pine dominated with 38% of basal area (Table 8).

In Group 1, other softwood species are the next highest contributor to total basal area (17%), but hardwoods are similar (14%). Other than white pine, Group 1 contains a fair amount of red pine and sugar maple (7% and 6%, respectively). Group 2 contains twice as much hardwood basal area (28%) than other softwood species (12%). After white pine, the group contains a lot of red oak, sugar maple, and hemlock; combined these species contribute 24% of total basal area in the group. Group 3 is largely white pine (63%) and hardwood (31%) with only a small percentage of basal area being contributed by other softwood species (6%). Group 3 primarily consists of red oak (12%) and sugar maple (11%) in addition to the dominating white pine. The species composition in Group 4 is more even, with other softwood species and hardwoods contributing similar amounts to total basal area as white pine (29%, 37%, and 34%, respectively). Grouped, hardwoods contribute most to total basal area in this group, but white pine is still the dominate single species. Hemlock, red oak, red pine, sugar maple and black birch are also large contributors, accounting for 51% of total basal area. In Group 5, the group containing all untreated plots, the division among white pine, other softwood (29%), and hardwood (33%) is also more even as in Group 4. Other than white pine, Group 5 contains a lot of sugar maple (19%), red pine (13%) and red spruce (8%) (Figure 4).

To help understand the relative performance of each treated group versus the untreated group, a chi-square test was conducted for sawlog grade distribution for all tree species in our plots. Tree grades 1, 2 and 3 were considered while grade 4 trees were omitted because such trees only contain pulpwood. At the 0.05 significance level our test yielded a significant result as $p = 0.000002903$ (Table 12). Grade 1 trees were uncommon across all groups. Group 1 had no grade 1 trees. Groups 1 and 4 had proportionally fewer grade 1 trees than Groups 2, 3, and 5. Group 1 had proportionally much fewer grade 2 trees than the other groups. Overall sawlog grade distribution was not similar among groups (Table 13).

For 2019, internal rates of return of 7% were necessary for Groups 2 and 3 (Table 11). Groups 1 and 4 had negative difference values, therefore IRR cannot be calculated.

2a) All TSI versus All Untreated Results – Eastern White Pine

Combining all 97 TSI plots together for white pine only yielded an average 2019 sawtimber value of more than $1,030/ac. All untreated plots averaged a little more than $950/ac (Table 5).

At all interest rates, NPV are negative. The smallest negative value occurs at 2% with a loss of a little more than $35. When interest rates increased to 4% and 6%, the difference between the treated and untreated plots were ($102.87) and ($183.81), respectively (Table 6).

When the white pine trees from all TSI plots are combined total timber volume averages more than 8,000 bd. ft./ac. All of the untreated plots account for just under 7,800 bd. ft./ac. (Table 7). This small difference makes little contribution to the negative results for treatment.

In examining basal area as it relates to species composition, white pine makes up more than 50% of basal area by percentage when all TSI plots are combined. Hardwood follows next at almost 30% of basal area and other softwood species contribute 15% of total basal area. All untreated plots are more evenly distributed, but white pine still dominates with 38% of total basal area (Table 8).

A chi-square test was conducted for sawlog grade distribution of all TSI plots versus all untreated plots. Tree grades 1, 2 and 3 were considered, but grade 4 trees were omitted because such trees only contain pulpwood. At the 0.05 significance level our chi-square test produced a significant value ($p = 0.0328$) (Table 14). Grade distribution is not the same between groups – the group of all untreated plots contains a proportionally larger amount of grade 1 trees than the group with all treated plots (Table 15).

For a NPV of 0, an interest rate of 6% is necessary for white pine and an interest rate of 7% is necessary for all species in all TSI plots (Table 11).

2b) All TSI versus All Untreated Results – All Species

Total timber values were similar when all TSI plots and all untreated are combined into two groups for all tree species in our plots. For all TSI plots the total value equates to more than \$1,570/ac. Not very far behind is the combined untreated plots value of just over \$1,500/ac. Table 5).

As with the white pine only results, the difference in NPV is negative for the combined plots for all interest rates. The smallest loss takes place at 2%, with a loss of just under \$75.

Losses continue to rise from that point for 4% and 6% at ($140.51) and ($244.58), respectively (Table 6).

Timber volume, basal area and tree grades give us some insight into each of our timber values and the difference in NPV. The total volume of all tree species in our plots is just over 10,900 bd. ft./ac. for all TSI plots. For all untreated plots timber volume is a bit higher at more than 13,000 bd. ft./ac. (Table 7).

In examining basal area as it relates to species composition, white pine makes up more than 50% of basal area by percentage when all TSI plots are combined. Hardwood follows next at almost 30% of basal area and other softwood species contribute 15% of total basal area. All untreated plots are more evenly distributed, but white pine still dominates with 38% of total basal area (Table 8).

In the all TSI plots group red oak (11%), sugar maple (8%) and hemlock (6%) are the species, besides white pine, that contribute most to total basal area. In the all untreated plots group the distribution among white pine, other softwood (29%) and hardwood (33%) is more even. In addition to white pine, this group contains a large amount of sugar maple (19%), red pine (13%) and red spruce (8%) (Figure 5).

As before, the chi-square test conducted for sawlog grade distribution only includes tree grades 1, 2 and 3. The test yielded a non-significant value at the 0.05 significance level (p = 0.6443) (Table 16). The proportion of each tree grade is similar for both the treated and untreated plots (Table 17).

Discussion

1a) Group Discussion – Eastern White Pine

Group 2 has performed the best among the group results for eastern white pine over the time span of TSI treatments. At each interest rate, it maintained positive NPV, and the 2019 timber value is highest among all groups. This is likely due to the group containing the largest timber volume of the five groups. The group was also dominated by white pine, the target species of the TSI work, and it contained a higher proportion of grade 2 trees compared to the other groups.

Group 1 and Group 3 had similar timber volumes and values, but Group 3 had slightly larger values. Despite those close values, Group 3 obtained positive NPV at all interest rates while Group 1 only had a positive NPV at 2%. Group 3 had more grade 2 trees than Group 1, so its slightly higher value and better performance can be attributed to those better quality trees.

Group 4 was not financially successful after TSI treatment. At each interest rate, Group 4 had negative NPV. Group 4 had the lowest timber volume and value among all groups. This group was less dominated by white pine, having the fewest trees per acre, and these were predominantly grade 3, so they do not contribute as much to the per acre value.

Group 5, the group with all untreated plots, out-performed Group 4, and many of its results are similar to those of Group 1 and Group 3. A possible explanation for this is that the untreated plots of Group 5 may have already contained better quality trees, as evidenced by the proportion of higher quality tree grades compared to the other groups, so the forester may have decided that TSI was unnecessary in those areas.

We conclude that financial performance of white pine in our groups was mixed. Groups 1, 2 and 3 did well at lower interest rates, which is similar to the results from Pearson's study in

1935, but Group 4 did poorly. As interest rates rose, NPV, the difference between the treated and untreated groups, declined – only Group 2 and 3 remained positive at higher interest rates.

1b) Group Discussion – All Tree Species

The aggregate of all tree species in our plots produced similar results to those of the white pine group analysis. Group 2 again had the largest 2019 timber volume values among all groups. At each interest rate, Group 2 maintained a positive NPV. Group 2's high timber value may be attributed to a few factors – other than white pine, it contained twice the basal area of hardwood trees, which tend to be more valuable than softwood trees. Additionally, Group 2 had the most grade 1 trees of all groups and had proportionally more grade 2 trees than Group 1 and 4.

Group 3 has a similar timber value to Group 2, and NPV remained positive at all interest rates in the group. Group 3 contained a lower timber volume per acre than Group 2 and Group 5, but it was higher than Group 1 and Group 4. Only a small percent of total basal area is contributed by softwood species, so Group 3 likely maintains the positive NPV as a result of having more high value species such as red oak and sugar maple. Group 3 also had a proportionally larger amount of grade 2 trees compared to Groups 1 and 4.

Group 5 performed better than Groups 1 and 4 in terms of 2019 timber value and timber volume. Group 5 was slightly lower than Group 2 in terms of proportion of grade 1 trees, and it had proportionally more grade 2 trees than Groups 1 and 4, which is part of why it has done comparatively better than those groups. Group 1 and Group 4 have negative NPV at all interest rates as a result of their lower proportion of quality trees and lower per acre volume and therefore lower value.

We can conclude that, as with the white pine analysis, financial performance varied. While Groups 2 and 3 were able to maintain positive NPV, Groups 1 and 4 did not. Low interest rates appear to be key in the success of TSI from an economic perspective.

2a) All TSI versus All Untreated Discussion – Eastern White Pine

Despite a slightly larger 2019 timber value than the all untreated group, the all TSI group had negative NPV at all interest rates. This is due to the compounded costs negating the benefits of slightly higher timber value and volumes in this group that may be a result of TSI activities.

2b) All TSI versus All Untreated Discussion – All Tree Species

As with white pine in the all TSI group, 2019 timber value was larger than that of the all untreated group. Still, the all TSI group had negative NPV at all interest rates because the compounded costs were larger than the additional volume and values that may have resulted from TSI work.

Conclusion

Across our four timber evaluation scenarios we have seen mixed results. For most analyses, the groups that contained the highest timber volumes also contained the highest timber values and better quality trees. That was not the case for the all TSI versus all untreated of all species analysis; instead, the untreated group had a larger timber volume but lower timber value. At higher interest rates, the treated groups were not as successful at maintaining positive NPV. Though the TSI work was intended to enhance timber quality, it did not make any large changes. In some cases, compounded costs of treatments were simply too high to result in positive financial results.

As a case study, this research does not contain true controls, so it is difficult to determine if TSI alone enhanced Group 1, 2 and 3 in some of the evaluations. Other factors may have contributed to our results including that the forest was treated with TSI at an older age than recommended for TSI results to be most effective; the BHF's forest was at least 40 years old when TSI was conducted. It is possible that the trees were just too mature to fully benefit from treatment. Additionally, this forest may have been lacking in quality trees from the start of the TSI work, too, since even Group 5, consisting of all untreated plots, contained a very small amount of high quality grade 1 trees.

CHAPTER 2

Introduction

New England forests are composed of a variety of forest types and tree species. The spruce-fir forest type is dominated by balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*). Northern hardwood forests contain American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*). Transition forest types contain softwood species, such as eastern white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*), and hardwoods such as northern red oak (*Quercus rubra*) (Foster 1995). Each of these forest types are present in New Hampshire, and each species contributes to the state's economy.

Forests provide numerous products and ecosystem services that affect economies and environmental quality. Timber may be sold for uses such as furniture, construction materials, paper, and as an energy source. Trees and deadwood, in the form of snags and coarse woody debris (CWD), provide a multitude of ecosystem services including food and habitat for a suite of native wildlife species as well as carbon sequestration.

New Hampshire is the second most forested state in the country with 84% of its land mass covered in forest. This makes forests an important resource for the state's economy. In 2013 the annual value of sales from forest products, such as those mentioned above, was estimated to be $1.4 billion. Forest-based recreation typically matches that yearly contribution to the state's economy (NEFA 2013). High-quality timber and forest-based recreational opportunities are especially important to the state's rural economy.

To achieve economic and ecosystem objectives, landowners apply silvicultural treatments to support ecosystem functions as well as health and productivity of forests (Nyland et al. 2016).

Management of forests held by families and small organizations is supported by public programs that encourage active treatment of the nearly 35% privately-owned forestlands across the United States. Public cost-share programs are often utilized by landowners to financially support the management activities they implement (Stoots et al. 2017). These programs provide incentives for landowners to conduct activities such as timber stand improvement (TSI) on their forestlands.

A modest amount of research has been done on the effectiveness of cost-share programs. Most of these studies, however, are primarily focused on the effectiveness of cost-share programs rather than the financial performance of the management activity. For example, Arbogast (2015) summarized incentive programs of each state for small landowners. Some states have incentive programs for TSI activities, but this study only provides results about how effective these programs are rather than the outcomes of the treatment. Similar studies have been conducted by Jacobson et al. (2009) and Stoots et al. (2017). Researchers suggest that those who seek not only timber value but also nontimber values from their forest are more likely to invest in forest management with the support of cost-share programs (Hyberg and Holthausen 1989, Kilgore et al. 2015).

Timber stand improvement (TSI) is a broad class of silvicultural practices that aim to improve future timber outcomes and provide ecosystem benefits. One objective of TSI is to reduce competition around chosen crop trees – those with the best potential for high quality in the future. Girdling is a TSI technique that involves cutting a ring around the sapwood at the base a tree to kill it (Nyland et al. 2016). The girdled trees die in place, creating deadwood including snags, which eventually fall, contributing to CWD. The financial objective is to focus the productivity of the stand on the more economically valuable trees. For our case study, white pine was the targeted economically valuable species. TSI is a strong choice for small forest landowners because it is a short-term, low cost management practice that can provide high returns (Anderson 1975).

Girdling, as a TSI practice, not only has the ability to enhance timber quality for financial gain, but it also creates additional deadwood that provides ecosystem services. There are many ecosystem services provided by living trees, dead trees, soil, leaf litter, plants and other forest components. These services do not have market values, so protecting them is often not considered in economic decisions. To slow the effects of climate change and continue to provide a sustainable source of resources for human life, forests must be responsibility managed (Jenkins and Schaap 2018). We evaluate the additional benefit of ecosystem services that arise from TSI treatments to make a case as to why treatment can be useful beyond improving timber quality. Our study focuses on the contributions of TSI to the creation of deadwood in the form of snags and CWD as wildlife resources and carbon storage mechanisms.

Snags are standing dead trees that have lost most of their leaves and limbs. Typically, they are considered snags if they stand over 20 feet tall and are considered a stub if they stand under 20 feet tall (Thomas et al. 1979). As a wildlife resource, a snag is any dead standing tree that is three inches in diameter at breast height and at least six feet tall (CT DEEP 2020) – for our case study, any standing dead tree regardless of height was recorded. Standing deadwood, including snags, can be created as a result of natural causes or by deliberate girdling or cutting in a TSI treatment.

Several bird species, including woodpeckers, require cavities for roosting and nesting and snags provide these cavity opportunities (Hagan and Grove 1999). Snags are beneficial to more than just cavity-nesting birds. Squirrels and raccoons may use cavities for their nests or as hiding places to store food. A snag may contain food sources such as mosses, lichen, insects and fungi that are eaten by a variety of wildlife species. Moss, lichen and fungi also return nutrients to the soil, which improves functionality (NWF 2020). In the northeastern United States alone there are 28 bird, 18 mammal, 23 reptile/amphibian and hundreds of vertebrate and fungi species that utilize dead wood from snags and CWD (Hagan and Grove 1999).

Research conducted in North Carolina investigate the relationship between the number of snags in a forest and presence of cavity nesting bird species. Well-decayed snags are important for the success of many primary cavity-nesting birds because they provide invertebrate foraging opportunities. The researchers discovered that, although their study area contained fewer snags than what experts recommend should be available for birds, there were still nine species of cavity-nesting birds in the study area that utilized the snags that were present (Homyack et al. 2011).

Moriarty and McComb (1983) also examined wildlife outcomes of TSI treatment. They found that up to 30 years after girdling additional feeding substrate and nesting areas were available for primary cavity nesting species such as pileated woodpeckers (*Dryocopus pileatus*) from the presence of snags.

Coarse woody debris (CWD) includes all woody material, no matter the source, that is dead and lying on the forest floor (Hagan and Grove 1999). Many animal species depend on CWD as sites for shelter or food. CWD can promote soil stability by protecting the forest from runoff or erosion. The decaying of CWD releases nutrients into the soil that can aid in tree growth and quality.

Coarse woody debris also contributes to forest structure and function, and it influences multiple forest processes such as wildlife habitat, erosion, and carbon storage. CWD decomposes at relatively slow rates, so it is one form of a long-term carbon storage pool. About 8% of the carbon stock is contained by deadwood throughout the world's forests, and in the northeastern US deadwood in temperate forests accounts for roughly 20% of aboveground biomass (Campbell et al. 2019).

Combined, live and dead trees store nearly 60% of carbon in forest ecosystems. Carbon dioxide and other greenhouse gases have seen an increased presence in the atmosphere since the Industrial Revolution due to fossil fuel energy use and shifts in land use for development and agriculture. Carbon offsets may come from an entity that is able to reduce their greenhouse gas emissions to compensate for the extra emissions another organization emits beyond the allowable limit. These offsets can come in the form of carbon that is physically stored in a forest or forest products (McKinley et al. 2011). This makes carbon storage an important component to climate change mitigation. Landowners that practice appropriate and useful forest management techniques can enhance their carbon storage capacities. Forest management techniques can potentially increase forest carbon stocks by increasing growth rates. Increased growth rates mean increased wood production and carbon stock.

There are not many previous studies of ecosystem impacts of TSI treatments. Of those that exist, none of them took place in New England forests. Additionally, there are no studies linking TSI work to carbon storage potential, something we aim to examine in this study.

To further understand the ecosystem services outcomes of TSI treatment, we examine the case of a series of TSI treatments conducted from 1999 to 2003 on a large private forest in Strafford, New Hampshire. The landowner, the Blue Hills Foundation (BHF), owns more than 7,000 acres that are primarily forested with some small areas of farmland and various water features. When TSI activities were conducted, the foundation was interested in the financial gain from creating better quality timber, but today its objectives are multifaceted and include ecosystem services interests. The foundation's records indicate the types of TSI activities that took place, where they occurred and how much the work cost, including public cost-share payments from the Natural Resources Conservation Service (NRCS). By contrast, there are no biometric data on the stands at the times of treatment.

It is possible that TSI treatment does not improve living tree quality enough to provide a positive NPV when comparing treated sites to untreated sites, which could lead to the conclusion that it is not a worthwhile treatment; however, if we look beyond the finances of TSI to include an ecosystem services evaluation, we may obtain results that would support TSI treatments by landowners interested in ecosystem gains from TSI treatment.

Landowners would benefit from access to information that can help them determine if TSI is worthwhile for their forest. We use our field-collected data to determine if ecosystem services may be enhanced with TSI. We apply those outcomes with timber-based outcomes to determine the overall outcomes of TSI activities. We hope this case study will help bridge knowledge gaps and provide a framework by which other forest landowners can make decisions about the applicability of TSI practices on their forests. Our objectives for this project are (1) to determine if ecosystem services are enhanced by TSI treatment and if so, (2) to determine if the enhancement is enough to justify the implementation of TSI, even if the treatment will not simultaneously enhance timber quality and value.

Methods

Timber quality improvement is often not the only landowner objective when conducting forest management treatments. Ecosystem services are an additional benefit that should be considered when evaluating the effectiveness of a forest management treatment method. The goals of this project are to determine if a limited set of ecosystem services, deadwood in the form of snags and CWD, were enhanced by TSI activities. If they are, we will determine if those enhancements were enough to justify TSI as a worthwhile treatment when the same treatment did not enhance timber enough for a positive NPV. This can be done by converting biometric ecological services data, such as deadwood volume, into financial values and adding them to the timber values calculated in Kalp and Howard (2020, forthcoming).

Site Description

Research for this project was conducted on land owned by the Blue Hills Foundation in Strafford, New Hampshire, USA (Figure 6). All sample plots are located between 550 and 850 feet in elevation (USDA NRCS 2019). The dominant soil types include fine sandy loam, very rocky fine sandy loam and areas of loamy sand (UNH Extension 2019). The sampling area generally consists of rolling hills with some steep areas and special features including a large waterfall, portions of Big River, an old mica mine and small ponds. In the southern portion of the study area slopes mostly face northeast as they approach the center of the property. From the northern portion of the study area, slopes face southwest as they approach the center of the property. The forest in the sampling area is dominated by conifers, most of which are eastern white pine with some eastern hemlock scattered throughout. In small portions of the sampling area, hardwood species dominate. Approximately 70 years ago, prior to BHF's acquisition of the land, much of the sampling area had been commercially clearcut.

From 1989 to 2003, TSI activities were completed on 2,000 acres of the more than 7,000-acre land-holding. The TSI methods utilized most were girdling larger diameter trees and cutting down smaller diameter trees to release crop trees. All trees that were cut or girdled were left on site rather than being removed from the property. Some pruning was also completed, but the BHF's records are not adequate to locate those treatments and there was little evidence of pruning observed in the sampling area. In most locations the landowners were releasing eastern white pine crop trees, so smaller white pines or other less desired species were cut or girdled. A consequence of the treatment is the additional deadwood, in the form of snags and CWD, found throughout the plots; these forms of wood provide wildlife habitat resources and carbon storage as a by-product of actions taken to obtain better quality pine growth.

Biometric Data Collection

Biometric data on treated and untreated stands were collected from May to August 2019. Hand-drawn maps provided by the landowners were digitized in ArcGIS, and ArcGIS was used to map transects within TSI-treated areas. On average, four chains (264 feet) were maintained between plots within and between each transect. Before setting up each plot, a visual inspection of the area was completed to confirm that the plot was within a TSI area, as evidenced by cut and girdled trees. Because treatments were applied for management rather than experimental purposes, we do not have true experimental control plots. Instead, untreated plots were located in untreated patches within treated stands and in proximate untreated stands with similar forest characteristics to serve as what will be referred to as untreated plots.

We calculated the coefficient of variation using data from our initial samples to determine the sampling intensity needed for a 90% probability of achieving a 10% error. We actually measured more plots than determined by the sampling intensity calculation: 97 TSI (treated) plots and 30 untreated plots (Figure 7).

Each fixed-radius plot was one-tenth of an acre (radius = 37.5ft.) (Figure 8). Within the plot boundary, in addition to living tree data, which can be found in Kalp and Howard (2020, forthcoming), all deadwood products, such as CWD, snags, and other standing deadwood, were measured due to their ecological contributions including wildlife benefits and carbon storage. We categorized deadwood as CWD if it was lying on the ground. We considered any standing dead tree, based on visual inspection of the crown, as standing deadwood. In our analysis, we separated standing dead trees that were more than 3 inches in diameter and at least six feet tall as snags (CT DEEP 2020).

In each 0.10 acre plot, CWD and snag information were collected. For all standing deadwood within the plot the following were recorded: species (if known), height, DBH, type and decay class. Height was measured with the TruPulse 200 laser hypsometer, and a diameter tape was used for DBH. Snag type was recorded as girdled, cut, natural or unknown based on visual observation. Decay class was labeled 1-9 based on Thomas et al. (1979) (Figure 9).

The line-intercept method was used to measure CWD (of at least four inches in diameter) in each plot. A random azimuth was generated, and a 100-foot measuring tape was used to lie across the diameter of the plot (75 feet), passing through plot center, along the generated azimuth (Figure 8). For any CWD that crossed the measuring tape for the diameter of the plot, the following data were collected: species, diameter, length, angle off the ground, ground slope, and decay class. Angle off the ground was calculated when CWD was not lying flat to the ground because when not lying flat it has a shorter effective length, which reduces the possibility of the piece crossing the transect (Marshall et al. 2000). Length was recorded by determining the center axis of the CWD, based on Marshall et al. (2000) and using a TruPulse 200 laser hypsometer. Diameter was measured using calipers. A clinometer was used for measuring angle off of the ground and ground slope. Decay class of CWD was labeled 1-5 based on Thomas et al. (1979) (Figure 9).

Although not pertinent to our analysis of deadwood as snags and CWD, we also collected data on understory vegetation. The CWD line-intercept line was used to locate two understory mil-acre (radius = 3.7 ft.) plots. These subplots provide understory data regarding which tree and herbaceous plant species are attempting to regenerate in the forest. Each subplot was located on either side of plot center equidistant between plot center and the edge of the plot. For each subplot information was reordered for the number of saplings (> 4 ft.) and number of seedlings (< 4ft.) of each identified species.

Grouping the Data

The BHF conducted TSI from 1989 to 2003, a span of 15 years. With a large number of plots in the treated area (97), it was logical to group the plots for a more finite look at how TSI treatment has affected the forest. To create these groups, we conducted a cluster analysis using PC-ORD (McCune and Grace 2019). This did not provide us with any clear distinctions among plots, so we subjectively grouped the plots into five groups based on the chronological years of treatment. We attempted to make number of sample plots in each group as even as possible while maintaining chronological order (Table 18). Group 5 contains all untreated plots. We also examine all treated plots versus all untreated plots.

Biometric Data Analysis

Once all data were collected, we calculated volume per acre (ft.^{3}/ac.) and pieces per acre (#/ac.) of standing deadwood and CWD for each of the five treatment groups as well as for all TSI plots versus all untreated plots. Snag data were extracted from the standing deadwood for a separate evaluation. All calculations were done using appropriate equations in Microsoft Excel.

We also conducted chi-square tests to determine if there were any significant differences in decay class distribution of our CWD, standing deadwood, and snags. We completed six total chi-square tests: decay class distribution of standing deadwood for all five groups, decay class distribution of snags for all five groups, decay class distribution of CWD for all five groups, decay class distribution of standing deadwood for all TSI plots versus all untreated plots, decay class distribution of snags for all TSI plots versus all untreated plots, and decay class distribution of CWD for all TSI plots versus all untreated plots. The chi-square tests for the snags and standing deadwood do not include any grade 1 or 2 snags because those are considered living trees in the decay classification we used (Figure 9). For the CWD chi-square tests we only include number of observations of pieces of CWD, so observations of zero pieces along a transect in a plot are not included. All four tests were conducted at the 0.05 significance level.

Deadwood Valuation

We have previously evaluated the financial performance of TSI treatments on timber value for this case study (Kalp and Howard, 2020, forthcoming). In cases in which net present value (NPV), the difference between the value of the untreated group and treated group, is negative and the treated group has a greater volume of deadwood than the untreated group, we determine an implicit value for deadwood required to breakeven with TSI versus without the treatment. Groups 1 and 4 had the requisite negative NPV at all interest rates. We combine volume values for standing deadwood and CWD because both contribute to ecosystem services such as wildlife habitat and carbon sequestration.

We apply the capital accumulation formula (Davis et al. 2001) to determine the amount needed to accumulate the 2019 loss from our timber-based evaluation, from the midpoints of the treatment periods (1990, 29 years ago, for Group 1; 2001, 18 years ago, for Group 4):

$$a = (V_{2019} * r) / ((1+ r)^n – 1) \qquad \text{(Equation 1)}$$

where a is the annual value per cubic foot per year, V equals the 2019 NPV, r equals the interest rate, and n equals the number of years since treatment (29 in the case of Group 1 and 18 in the case of Group 4). The result is the annualized value of a cubic foot per acre per year. The additional value of deadwood per acre is found by multiplying the result of Equation 1 by the additional per acre amount of deadwood obtained by treatment. We annualize the value to recognize that deadwood provides ecosystem services continuously. The capital accumulation formula is equivalent to the equal annual equivalent formula used to compare investments of different durations (Davis et al, 2001). Therefore, the calculated values obtained from the calculations for Groups 1 and 4 are directly comparable although the treatments were done 11 years apart.

Results

Using field data, we calculated biometric values including mean volume per acre and mean pieces per acre for standing deadwood and CWD with a sub-analysis of snags. Results for these analyses are presented in two sections: 1) standing deadwood, snags and CWD for the five groups (four groups defined by treatment period and one group consisting of untreated plots) and 2) standing deadwood, snags and CWD for all TSI plots versus all untreated plots. For each section, we first examine our biometric data including volume per acre and pieces per acre. Next, we analyze the results of our chi-square tests to determine if they indicate any significant difference in decay class distribution of our deadwood, snags, or CWD across all groups. Finally, we refer to the timber results of our financial model (Kalp and Howard 2020, forthcoming) to examine the implicit value of deadwood required to breakeven in instances where NPV was negative.

1) Group Results – Standing Deadwood, Snags & CWD

We can examine the biometric data of our standing deadwood and CWD, as well as snags, to calculate mean volume per acre (ft.^{3}/ac.) and mean pieces per acre (#/ac.). Standing deadwood volume per acre is largest for Group 4 (1488.8 ft.^{3}/ac.). Group 5, our group containing all untreated plots, contains the smallest volume per acre at 936.8 ft.3/ac. Among the other treated groups, Group 2 has the next largest volume per acre at 1209.4 ft^3/ac. Group 1 is fairly close to Group 5 at 996.1 ft.^{3}/ac, and Group 3 is in between the other groups with a volume per acre value of 1073.2 ft.^{3}/ac. (Table 19).

Group 5 had the smallest mean volume per acre, and this group also has the smallest number of standing deadwood per acre (80). Among the treated groups, the patterns did not follow those from volume per acre. Group 1, with the second lowest volume per acre, has the largest number of standing deadwood per acre (190). Group 4, with the largest volume per acre, has the second largest number of standing deadwood per acre (170). Group 2 has the second highest volume per acre value, but it has the fewest standing deadwood per acre (140) of all treated groups. Group 3 was in the middle for volume per acre and it continues that trend for standing deadwood per acre (160) (Table 19).

As with standing deadwood, Group 4 contains the largest snag volume per acre with 1289.4 ft.^{3}/ac. Group 1 contains the smallest snag volume (749.1 ft.^{3}/ac.), which is lower than that of Group 5 (808.7 ft.^{3}/ac.), the group consisting of all untreated plots. Group 3 is slightly larger than Group 5 with 865.7 ft.^{3}/ac. Group 2 has the second largest snag volume per acre (1010.1 ft.^{3}/ac.) (Table 20).

Snags per acre are similar in all groups. Group 3 has the smallest number of snags per acre (33), and Group 2 contains the largest number of snags per acre (41). Group 4, with the largest snag volume per acre, has the second largest number of snags per acre (40), so it falls right behind Group 2. Group 5 contains 38 snags per acre, and Group 1 contains 37 snags per acre (Table 20).

Mean volume per acre of CWD was largest for Group 3 (195.9 ft.^{3}/ac.) and smallest for Group 5, the group containing all untreated plots, at about 160 ft.^{3}/ac. Groups 1 and 4 have nearly identical with volume values of 185.4 ft.^{3}/ac. and 185.7 ft.^{3}/ac., respectively. Group 2 was slightly lower, at just under 180 ft.^{3}/ac. (Table 21).

As with snags, CWD pieces per acre do not follow the same pattern as volume per acre. Group 1 has the largest number of pieces per acre (98.8), and Group 5 has the smallest number

(45.4). Groups 2 and 3 have nearly identical pieces per acre values at 73.9 and 73.7, respectively. Group 4 contains 62.4 pieces per acre (Table 21).

We conducted chi-square tests to determine if there were significant differences in decay class distribution among the five groups for standing deadwood, snags, and CWD. For the standing deadwood and snags, we did not include decay classes 1 and 2 because they are not considered dead trees in the decay class guidelines (Thomas et al. 1979). We found a significant difference in decay class distribution of standing deadwood at the 0.05 significance level ($p = <0.00001$) (Table 22). In all groups, grade 7 was the most common decay class. Groups 1 and 4 had proportionally less grade 3 and 4 standing deadwood, and Group 2 had proportionally fewer grade 5 standing deadwood compared to the other groups (Table 23).

As with standing deadwood, our chi-square test for snags does not include decay classes 1 and 2 because those are living trees based on our decay class guidelines (Thomas et al. 1979). At the 0.05 significance level, we conclude a significant difference in snag decay class distribution of our five groups ($p = <0.00001$) (Table 24). Group 2 was the only group that had any decay class 9 snags (1). Groups 2, 3 and 4 have proportionally more grade 3 snags than Groups 1 and 5. Group 4 had proportionally fewer decay class 4 snags, and Group 3 had proportionally fewer decay class 7 snags compared to the other groups (Table 25).

Our chi-square test for decay class distribution of CWD was based on the number of pieces of CWD counted in each plot, so observations of zero pieces are not included. At the 0.05 significance level our test yielded non-significant result as $p = 0.093$ (Table 26). Grades 3 and 4 were the most commonly occurring decay classes for all groups. Among the groups, decay class distribution is relatively similar (Table 27).

2) <u>All TSI versus All Untreated Results – Standing Deadwood, Snags & CWD</u>

Biometric data were calculated as mean volume per acre (ft.^{3}/ac.) and mean pieces per acre (#/ac.) for standing deadwood and CWD with a sub-analysis of snags for the all TSI group and the all untreated group. The all TSI group had a larger standing deadwood volume per acre than the all untreated group (1207.6 ft.^{3}/ac. and 936.8 ft^3/ac., respectively) (Table 28).

Standing deadwood mean per acre follows the same trend - the all TSI group contains 160 standing deadwood per acre, more than the all untreated group, which contains half that number at 80 standing deadwood per acre (Table 28).

Mean snag volume per acre is larger for the all TSI group (1005.4 ft.^{3}/ac.) than the all untreated group (808.7 ft/^{3}/ac.) (Table 29).

Snags per acre follow the same pattern as snag volume per acre. The all TSI group has a larger snag per acre value (38). Though lower, the all untreated group snags per acre value (37) is not far behind the all TSI group (Table 29).

For CWD, mean volume per acre was largest in the all TSI group (187.3 ft.^{3}/ac.). The mean volume per acre of the all untreated group was a bit lower at 159.7 ft.^{3}/ac. (Table 30).

Unlike snags, the CWD mean pieces per acre trend was the same as the volume per acre. The all TSI group contains more pieces per acre (78.7) than the all untreated group, which contains 45.4 pieces per acre (Table 30).

Chi-square tests were conducted to detect any significant differences in decay class distribution among standing deadwood, snags, and CWD between treated and untreated groups. Our standing deadwood and snag chi-square tests do not include decay classes 1 and 2 because those are considered living trees (Thomas et al. 1979). Our standing deadwood test yielded a significant result at the 0.05 significance level (p = < 0.000001). Decay class 7 was the most commonly occurring standing deadwood class for all TSI and all untreated plots. The all TSI plot group has the least decay class 3 standing deadwood, and the all untreated plot group contains the least number of decay class 9 standing deadwood (Table 31). The all untreated group contains a proportionally larger amount of decay classes 3 and 4 compared to the all TSI group. The all TSI group contains a proportionally larger amount of decay class 7 standing deadwood compared to the all untreated group (Table 32).

The chi-square test for decay class distribution of snags does not include decay classes 1 and 2 because they are living trees in guidelines (Thomas et al. 1979). The chi-square test yielded a non-significant value ($p = 0.394458$) at the 0.05 significance level for difference in decay class distribution between the all TSI group and all untreated group (Table 33). There were similar proportions of each decay class for the all TSI group and the all treated group (Table 34).

For CWD decay class distribution we used the number of pieces of CWD counted in each plot, so observations of zero pieces have not been included. Our chi-square test yielded a non-significant result at the 0.05 significance level ($p = 0.1435$). For the all TSI plot group decay classes 3 and 4 were most common, but for the all untreated group decay classes 2 and 3 were most common. The lowest number of CWD pieces were in decay classes 1 and 5 for both groups (Table 35). The proportion of each decay class was similar between the two groups (Table 36).

Deadwood Valuation Results

We calculated the implicit value of deadwood based on standing deadwood and CWD volumes of Groups 1 and 4 to determine the value per cubic foot per year necessary to breakeven based on compounded input cots. For both groups, as interest rate increases, implied value to achieve the breakeven point decreases. In Group 1, at 2%, 4% and 6%, implicit values ($\$/ft.^3/yr.$)

are \$0.096, \$0.087, and \$0.084, respectively. Values are higher in Group 4 at \$0.034 (2%), \$0.032 (4%), and \$0.031 (6%) (Table 37). At all interest rates, for Groups 1 and 4, less than ten cents per acre per year is the necessary value to achieve a breakeven point based on compounded input costs.

Discussion

1) Group Discussion – Standing Deadwood, Snags & CWD

There are proportionally more decay class 7 standing deadwood in each group compared to the other decay classes. Despite how much time has passed since TSI was conducted, or if TSI was not conducted, decomposed stubs were most common. Group 5, consisting of all untreated plots, had the largest proportion of grade 3 standing deadwood, and second largest proportion of snags, which are the least decayed deadwood based on Thomas et al. (1979). Cutting and girdling trees has apparently sped up the decomposition process in our treated groups, as evidenced by lower proportions of the higher grade decay classes in most groups compared to Group 5.

Decay class 3 standing deadwood is taller than the other decay classes, which may contribute to Group 5 containing a standing deadwood volume per acre comparable to the treated groups while also containing the lowest number of standing deadwood per acre. The opposite occurs in Group 1, where standing deadwood volume is smallest, yet it has the largest number of standing deadwood per acre. Generally, pieces per acre declines as groups decrease in time since TSI was conducted – as more time passes, more trees fall from being cut or girdled and they decompose more, contributing to lower volume per acre values.

Snag per acre numbers are similar in all groups despite varying volume values, so treatment may not have as big of an influence on larger pieces of standing deadwood. Volume does appear to be influenced by treatment, though, since one of the lowest snag volume per acre values occurs in the untreated group.

There is less of a difference in distribution of decay class for CWD among all groups. In most instances grades 3 and 4 were the most common decay classes for each group, which are

CWD pieces that have decaying bark and are more sunken into the ground. Group 5, with all of the untreated plots, has the highest proportion of decay class 1 CWD, which is likely due to less fallen trees from natural causes as opposed to intentional cutting and girdling that occurred in the treated groups.

As with standing deadwood, CWD pieces per acre decreases as time since TSI was conducted for each group decreases. Again, Group 5 contains the smallest number of pieces per acre because all of its CWD is attributed to natural causes. Cutting trees and not removing them from the site instantly creates CWD, so that is why our treated groups have larger pieces per acre counts. Volume per acre is more mixed, so it does not seem to follow any obvious pattern. If similar size trees were cut and girdled during TSI treatment, then that may be creating similar volume values.

2) All TSI versus All Untreated Discussion – Standing Deadwood, Snags & CWD

As with the group analysis, decay class distribution is different between the all TSI group and the all untreated group. Once again, the untreated plots contained proportionally more grades 3 and 4 standing deadwood compared to the treated groups. These decay classes are full standing tees that have yet to lose branches or break in half, so they are more likely to occur in plots where no intentional cutting took place.

Similar to the results in the all group discussion, standing deadwood per acre is higher for the all TSI group as well as volume per acre. Many of the standing deadwood and snags in the all TSI group have been created from intentional cutting, while the standing deadwood and snags in the untreated group mostly contain dead standing trees, so volumes are an inverse of pieces per acre.

Snag decay class distribution appears to be less influenced by treatment compared to an analysis by the five groups. By not including all standing deadwood and only focusing on six foot or taller snags, much of the deadwood collected in our plots is left out of this decay class distribution analysis. Bigger snags seem to be present regardless of TSI treatment or no treatment.

The decay class distribution of CWD in the all TSI versus all untreated groups was more consistent between the groups. The untreated group has a higher proportion of grade 1 CWD pieces than that treated group. As with the all group assessment, this is due to intentional cutting and girdling leading to trees that fall and begin to decay while plots that have been untouched having less of a chance of wood falling and becoming CWD.

Pieces per acre is larger for the all TSI group than the all untreated group. Cutting trees as part of TSI treatment instantly creates pieces of CWD, so the group contains more pieces per acre. Volume per acre is larger for the all TSI group, but the volume per acre of the untreated plots is still fairly large in comparison. Even with decayed CWD pieces there is still so much that has fallen that volume is larger than that of the untreated plots where all CWD is natural.

Deadwood Valuation Discussion

Although all treated groups had more deadwood than the untreated group, Groups 2 and 3 had positive financial results from treatment (Kalp and Howard 2020, forthcoming) and are not used to estimate the value of ecosystem services from deadwood. Groups 1 and 4 had negative NPV, so their associated data provides estimates of the annualized dollar value per cubic feet to breakeven on the TSI investment. Group 1 had smaller negative NPV than Group 4, so Group 1 has smaller implicit costs (2% - $0.096, 4% - $0.087, 6% - $0.084) for deadwood to reach a breakeven point than Group 4 (2% - $0.032, 4% - $0.032, 6% - $0.031). We see our implicit values decrease as interest rate increases because value accumulates more rapidly at higher interest rates. For our case study, no more than ten cents per cubic foot per year would be necessary to reach a breakeven point via the implicit value added to our plots by ecosystem services provided by snags and CWD.

Using the highest ($.096) and lowest ($.031) implicit values from Groups 1 and 4, we calculated a range of additional value of deadwood in terms of provided ecosystem services for Groups 2 and 3, which both maintained positive NPV in our financial assessment (Kalp and Howard 2020, forthcoming). Assuming deadwood is worth about $0.03-$0.10 per cubic foot per year, the additional volume of deadwood in Group 2 (291.9 $ft.^3/ac.$) can be accounted for an additional $630-$2,250. Group 3 can provide roughly $305-$1,230 based on its additional volume (577.9 $ft.^3/ac.$). These values are not intended to be additional market value but to serve as a basis for interpretation by the landowner based on an implicit value ranging from $0.03 to $0.10 per cubic foot per year.

Conclusion

Across our standing deadwood, snag, and CWD evaluations we have seen mixed results. Standing deadwood and CWD decay classes appear to be influenced by TSI treatment, while combining all treated groups for snags are not. One thing that has remained true among the standing deadwood and CWD evaluations is that as a group decreases in years since TSI treatment, the pieces per acre of standing deadwood and CWD also decreases. This appears to indicate that cutting and girdling instantly create standing deadwood, snags, and CWD. Over time, these forms of dead wood decay, and the older groups have had the most time for trees to die or fall as a result of TSI treatment. Snag values are similar among all groups, so perhaps these larger standing deadwood pieces can only maintain so much space before they break off and become smaller standing deadwood or CWD. The smaller pieces per acre values and largest volume per acre values in the untreated plots suggest that no treatment creates standing deadwood, snags, and CWD, but they are less decayed and less common since they are from natural causes only. It is promising to see that standing deadwood, snag, and CWD volumes are larger in the treated groups than the untreated group. This suggests that TSI can enhance ecosystem services provided by deadwood.

It is ultimately up to the landowner to decide if an additional yearly per acre value for the added ecosystem services from standing deadwood, snags and CWD is sufficient for any negative financial outcome from a timber perspective. Our deadwood valuation indicates that there is range of values that may be necessary based on interest rate fluctuations, but nonetheless a landowner would see an increase in volume of all standing deadwood, even as snags, and CWD if they utilized TSI.

CONCLUSIONS

Chapter 1

Chapter 1 was focused on the timber component of a series of TSI treatments that took place from 1989 to 2003. Living tree data were compiled into biometric data including timber volume, timber value, species composition (as percent basal area) and decay class distribution of sawlogs. The analysis examined net present value (NPV) as of 2019 by comparing the difference between untreated plots and treated plots.

Across our four timber evaluations scenarios we have obtained mixed results. For most analyses, the groups that contained the highest timber volumes also contained the highest timber values and better quality trees. That was not the case for the all TSI vs. all untreated of all species analysis; instead, the untreated group had a larger timber volume but lower timber value. At higher interest rates, the groups were not as successful at maintaining positive NPV. Though the TSI work did enhance timber quality, it did not make any large changes. Compounded costs of treatment were simply too high for Groups 1 and 4. Groups 2 and 3 provided positive results due to these groups having the larger timber volumes of all groups, having larger proportions of higher quality trees and containing a large component of white pine, the target species of the TSI work.

This study does not contain true controls, so it is difficult to determine if TSI alone enhanced Group 1, 2 and 3 in some of the evaluations. Other factors may have contributed to our results including the fact that the forest was treated with TSI a bit later than it should have for TSI results to be most effective. TSI is most useful when conducted around 15-20 years of age, but the BHF conducted TSI to their forest when it was closer to 40 years old. It is possible that the trees were simply too mature at the time of treatment to fully benefit from treatment. This forest may have also been lacking in quality trees from the start of the TSI work, too, since even the untreated group, Group 5, contained a very small amount of high quality grade 1 trees.

Chapter 2

Chapter 2 examines ecosystem outcomes of the same series of TSI treatments that were examined in Chapter 1. Data were collected from deadwood in the plots in the form of standing deadwood (any size), snags (at least 3 inches diameter at breast height and 6 feet tall) and CWD. The data were used to calculate volume per acre, pieces per acre, and decay class distribution to determine if treatment enhanced any of these forms of deadwood. An economic valuation was completed for Groups 1 and 4, which had negative NPV in the Chapter 1 analysis. We calculated implicit value ($\$/ft.^3/yr.$) to breakeven based on compounded input costs.

Across our standing deadwood, snag and CWD evaluations we have seen mixed results. Standing deadwood decay classes appear to be influenced by TSI treatment, while all treated groups combined for snags and CWD decay classes are not. Among the standing deadwood and CWD evaluations, we found that as a group decreases in years since TSI treatment, the pieces per acre of standing deadwood and CWD also decreases. This appears to indicate that cutting and girdling instantly create standing deadwood, snags, and CWD. Over time, these forms of dead wood begin to decay, and the older groups have had the most time for living or standing trees to die or fall as a result of TSI treatment. Snag values are similar among all groups, so perhaps there is a threshold in which larger deadwood pieces can no longer maintain their size, so they break off and become smaller standing deadwood or CWD. The smaller pieces per acre values and largest volume per acre values in the untreated plots suggest that no treatment creates standing deadwood, snags and CWD, but they are less decayed and less common since they are from natural causes only. It is promising to see that standing deadwood, snag, and CWD volumes are larger in the treated groups than the untreated group. This suggests that TSI does enhance ecosystem services.

It is ultimately up to the landowner to decide if an additional yearly per acre value from additional ecosystem services from snags and CWD is sufficient to cover any negative financial results from a timber perspective. Our deadwood valuation indicates that there is range of input values that may be necessary based on interest rate fluctuations, but nonetheless a landowner would see an increase in volume of standing deadwood, snags, and CWD if they utilized TSI.

Final Thoughts

Our financial model has been turned into an easy-to-use Microsoft Excel document. Any landowner who has completed TSI work or intends to conduct it can input values regarding cost to conduct TSI, interest rates, and timber values (per acre) to determine their outcomes. Our research has indicated that TSI can create positive NPV at low interest rates and enhance ecosystem services in the forest in the form of snags and CWD.

The BHF utilized funds from the Natural Resources Conservation Service via a cost-share program to conduct TSI activities, but we evaluated NPV as the total cost, which included the BHF's cost and the cost-share program cost. Though we had some large negative NPV, these were not borne completely by the BHF.

As previously stated, the BHF never intended for their TSI work to be utilized for research, so our project serves as a case study of the impacts of TSI. We did not have true controls for this project, and treatment records were not as complete as the could have been. Additionally, the forest was treated with TSI at an older age than what is generally suggested for treatment to be most effective. Our biometric data were averages from our samples, so true values could be a bit lower or higher than what we actually calculated. The average sawlog values we used in our evaluation came from the southern tier of New Hampshire. It is possible that results would be different based on which part of the state or what other New England state this project was being completed in. Moreover, timber markets have changed since the BHF first started their TSI treatments. Had prices continued on the upward trend that had occurred during most of the years in which TSI treatments were accomplished, our financial results may have improved.

For future TSI research purposes, a younger forest would be most beneficial. Surveying the forest prior to TSI work and having a TSI prescription written by a forester would keep information more organized. Using a property intended for research purposes would allow for proper control plots to compare the results of TSI treated forest versus untreated forest and the ability to collect data throughout the period between treatment and final surveying.

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TABLES

Table 1. Eastern white pine (*Pinus strobus* L.) log grading table based on Brisbin and Sonderman (1971).

Grading Factor	**Tree Grade 1**	**Tree Grade 2**	**Tree Grade 3**	**Tree Grade 4**
Minimum DBH (in.)	10	10	10	10
Minimum Face Requirements on Butt 16-ft. Section	Two full length or four 50% length good faces	No Good Faces Required	No Good Faces Required	Includes all trees not qualifying for Grade 3 or better
Maximum Sweep in Butt 16-ft. Section (%)	20	30	40	No limit

Table 2. Hardwood log grading table based on Hanks (1976).

Grading Factor	Tree Grade 1	Tree Grade 2	Tree Grade 3	Tree Grade 4
Length of Grading Zone (ft.)	16	16	16	No limit
Length of Grading Section (ft.)	Best 12	Best 12	Best 12	No limit
Minimum DBH (in.)	16	13	10	10
Minimum Length of Clear Cuttings (3 best faces)	5	3	2	All trees not qualifying for Grade 3 or better
Cull Deduction - Sweep (%)	9	9	50	No limit

Table 3. Plot groupings. Four groups (1-4) of TSI plots and one group (5) of all untreated plots.

	Treatment Years in Group	**Plots in Group (#)**
Group 1	1989, 1990, 1991	17
Group 2	1992, 1993, 1994	26
Group 3	1995, 1996, 1997, 1998, 1999	28
Group 4	2000, 2001, 2002, 2003	26
Group 5	N/A – Untreated Plots	30

Table 4. BHF's average cost of TSI work for each group, all TSI plots, and all untreated plots (nominal $/acre).

	All TSI	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5/ All Untreated**
Average TSI Cost	$73	$58	$64	$65	$102	N/A

Table 5. Total 2019 sawtimber values per acre ($/ac.) for each group, all TSI plots, and all untreated plots.

	All TSI	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5/ All Untreated**
White Pine	$1,031.49	$1,123.76	$1,350.86	$1,242.19	$424.87	$957.24
All Species	$1,571.86	$1,290.67	$1,886.33	$1,772.17	$1,228.22	$1,507.96

Table 6. Differences in 2019 net present values, including compounded TSI costs, for each group and all TSI plots from all untreated plots at selected interest rates (nominal $/acre).

		All TSI	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5/ All Untreated**
Average Cost of TSI ($/ac.)		73	58	64	65	102	N/A
White Pine	**2%**	($36.62)	$63.01	$285.74	$183.08	($678.33)	N/A
	4%	($102.87)	($15.14)	$214.49	$127.51	($738.35)	N/A
	6%	($183.81)	($104.71)	$165.89	$13.17	($810.20)	N/A
All Species	**2%**	($74.26)	($316.64)	$274.65	$166.50	($421.54)	N/A
	4%	($140.51)	($394.79)	$203.40	$110.93	($481.56)	N/A
	6%	($244.58)	($528.62)	$87.89	$26.84	($564.41)	N/A

Table 7. Total sawtimber volume values per acre (bd.ft./ac.) for each group, all TSI plots, and all untreated plots.

	All TSI	Group 1	Group 2	Group 3	Group 4	Group 5/ All Untreated
White Pine	8,043	9,253	10,547	9,392	3,294	7,788
All Species	10,905	11,230	13,186	11,561	7,703	13,064

Table 8. Species composition in 2019, as percent basal area (ft.^{2}/ac.), for white pine, other softwood, and hardwood for each group, all TSI plots, and all untreated plots.

	All TSI	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5/ All Untreated**
White Pine (%)	56	70	60	63	35	38
Other Softwood (%)	15	16	12	6	29	29
Hardwood (%)	29	14	28	31	36	33

Table 9. Total observed (#) white pine tree count by tree grade for each group. [p = 0.000047]

	Grade 1	Grade 2	Grade 3	Total
Group 1	0	11	121	132
Group 2	1	64	160	225
Group 3	1	59	160	220
Group 4	0	10	68	78
Group 5	3	40	111	154

Table 10. Proportion (%) of white pine by tree grade for each group.

	Grade 1	**Grade 2**	**Grade 3**
Group 1	0	8.3	91.7
Group 2	.4	28.4	71.1
Group 3	.5	26.8	72.7
Group 4	0	12.8	87.2
Group 5	1.9	26	72.1

Table 11. Results of internal rate of return (IRR) calculation. Each value is the average necessary interest rate for NPV = 0 for each group and all TSI plots.

	All TSI	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5/ All Untreated**
White Pine	6%	4%	7%	7%	N/A	N/A
All Species	7%	N/A	7%	7%	N/A	N/A

Table 12. Total observed (#) all species tree count by tree grade for each group. [p = 0.000002903]

	Grade 1	Grade 2	Grade 3	Total
Group 1	0	14	149	163
Group 2	8	86	203	297
Group 3	4	82	192	278
Group 4	1	45	169	215
Group 5	6	76	220	302

Table 13. Proportion (%) of all species by tree grade for each group.

	Grade 1	**Grade 2**	**Grade 3**
Group 1	0	8.6	91.4
Group 2	2.7	29	68.4
Group 3	1.4	29.5	69.1
Group 4	.5	20.9	78.6
Group 5	2	25.2	72.8

Table 14. Total observed (#) white pine tree count by tree grade for all TSI plots and all untreated plots. [p = 0.0328]

	Grade 1	**Grade 2**	**Grade 3**	**Total**
All TSI	2	144	509	655
All Untreated	3	40	111	154

Table 15. Proportion (%) of white pine by tree grade for all TSI plots and all untreated plots.

	Grade 1	**Grade 2**	**Grade 3**
All TSI	.3	22	77.7
All Untreated	1.9	26	72.1

Table 16. Total observed (#) all species tree count by tree grade for all TSI plots and all untreated plots. [p = 0.6443]

	Grade 1	Grade 2	Grade 3	Total
All TSI	13	227	713	953
All Untreated	6	76	220	302

Table 17. Proportion (%) of all species by tree grade for all TSI plots and all untreated plots.

	Grade 1	**Grade 2**	**Grade 3**
All TSI	1.4	23.8	74.8
All Untreated	2	25.2	72.8

Table 18. Plot groupings. Four groups (1-4) of TSI plots and one group (5) of all untreated plots.

Group	Treatment Years in Group	Plots in Group (#)
1	1989, 1990, 1991	17
2	1992, 1993, 1994	26
3	1995, 1996, 1997, 1998, 1999	28
4	2000, 2001, 2002, 2003	26
5	N/A – Control Plots	30

Table 19. Standing deadwood mean volume per acre ($ft.^3/ac.$) and mean standing deadwood per acre (#/ac.) for each group.

	Volume/Acre ($ft.^3/ac.$)	**Standing Deadwood/Acre (#/ac.)**
Group 1	996.1	190
Group 2	1209.4	140
Group 3	1073.2	160
Group 4	1488.8	170
Group 5	936.8	80

Table 20. Snag mean volume per acre ($ft.^3/ac.$) and mean snags per acre (#/ac.) for each group.

	Volume/Acre ($ft.^3/ac.$)	**Snags/Acre (#/ac.)**
Group 1	794.1	37
Group 2	1010.1	41
Group 3	865.7	33
Group 4	1289.4	40
Group 5	808.7	38

Table 21. CWD mean volume per acre (ft.^{3}/ac.) and mean CWD pieces per acre (#/ac.) for each group.

	Volume/Acre (ft.^{3}/ac.)	**Pieces/Acre (#/ac.)**
Group 1	185.4	98.8
Group 2	179	73.9
Group 3	195.9	73.7
Group 4	185.7	62.4
Group 5	159.7	45.4

Table 22. Total (#) observed standing deadwood by grade for each group. [p = <0.00001]

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Total
Group 1	5	24	52	68	100	54	20	323
Group 2	19	53	21	59	136	54	23	365
Group 3	30	45	59	57	137	94	31	453
Group 4	2	15	46	83	214	71	19	450
Group 5	31	34	39	40	63	38	9	254

Table 23. Proportion (%) of standing deadwood by grade for each group.

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
Group 1	1.5	7.4	16.1	21.1	31	16.7	6.2
Group 2	5.2	14.5	5.8	16.2	37.3	14.8	6.2
Group 3	6.6	9.9	13	12.6	30.2	20.8	6.8
Group 4	.4	3.3	10.2	18.4	47.6	15.8	4.2
Group 5	12.2	13.4	15.4	15.7	24.8	15	3.5

Table 24. Total (#) observed snags by grade for each group. [p = <0.00001]

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Total
Group 1	1	16	23	9	11	4	0	64
Group 2	14	32	14	23	12	10	1	106
Group 3	17	27	22	15	6	7	0	94
Group 4	1	10	26	32	30	5	0	104
Group 5	16	26	27	18	22	4	0	113

Table 25. Proportion (%) of snags by grade for each group.

	Grade 3	**Grade 4**	**Grade 5**	**Grade 6**	**Grade 7**	**Grade 8**	**Grade 9**
Group 1	1.6	25	35.9	14.1	17.2	6.3	0
Group 2	13.2	30.2	13.2	21.7	11.3	9.4	.9
Group 3	18.1	28.7	23.4	16	6.4	7.4	0
Group 4	1	9.6	25	30.8	28.8	4.8	0
Group 5	14.2	23	23.9	15.9	19.5	3.5	0

Table 26. Total (#) observed CWD pieces by grade for each group. [p = 0.093]

	Grade 1	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**	**Total**
Group 1	1	11	13	8	2	35
Group 2	5	16	19	19	2	61
Group 3	5	10	23	37	9	84
Group 4	4	11	27	21	4	67
Group 5	5	8	8	7	1	29

Table 27. Proportion (%) of CWD pieces by grade for each group.

	Grade 1	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**
Group 1	2.9	31.4	37.1	22.9	5.7
Group 2	8.2	26.2	31.1	31.1	3.3
Group 3	6	11.9	27.4	44	10.7
Group 4	6	16.4	40.3	31.3	6
Group 5	17.2	27.6	27.6	24.1	3.4

Table 28. Standing deadwood mean volume per acre ($ft.^3/ac.$) and mean standing deadwood per acre (#/ac.) for the all TSI group and the all untreated group.

	Volume/Acre ($ft.^3/ac.$)	**Standing Deadwood/Acre (#/ac.)**
All TSI	1207.6	160
All Untreated	936.8	80

Table 29. Snag mean volume per acre ($ft.^3/ac.$) and mean snags per acre (#/ac.) for the all TSI group and the all untreated group.

	Volume/Acre ($ft.^3/ac.$)	**Snags/Acre (#/ac.)**
All TSI	1005.4	38
All Untreated	808.7	37

Table 30. CWD mean volume per acre (ft.^{3}/ac.) and mean CWD pieces per acre (#/ac.) for the all TSI group and the all untreated group.

	Volume/Acre (ft.^{3}/ac.)	Pieces/Acre (#/ac.)
All TSI	187.3	78.7
All Untreated	159.7	45.4

Table 31. Total (#) observed standing deadwood by grade for all TSI plots and all untreated plots. [p = <0.000001]

	Grade 3	**Grade 4**	**Grade 5**	**Grade 6**	**Grade 7**	**Grade 8**	**Grade 9**	**Total**
All TSI	56	137	178	267	587	273	93	1591
All Untreated	31	34	39	40	63	38	9	254

Table 32. Proportion (%) of standing deadwood by grade for all TSI plots and all untreated plots.

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
All TSI	3.5	8.6	11.2	16.8	36.9	17.2	5.8
All Untreated	12.2	13.4	15.4	15.7	24.8	15	3.5

Table 33. Total (#) observed snags by grade for all TSI plots and all untreated plots. [p = 0.394458]

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Total
All TSI	33	85	85	79	59	26	1	368
All Untreated	16	26	27	18	22	4	0	113

Table 34. Proportion (%) of snags by grade for all TSI plots and all untreated plots.

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
All TSI	9	23.1	23.1	21.5	16	7.1	.3
All Untreated	14.2	23	23.9	15.9	19.5	3.5	0

Table 35. Total (#) observed CWD pieces by grade for all TSI plots and all untreated plots. [p = 0.1435]

	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total
All TSI	15	48	82	85	17	247
All Untreated	5	8	8	7	1	29

Table 36. Proportion (%) of CWD pieces by grade for all TSI plots and all untreated plots.

	Grade 1	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**
All TSI	6.1	19.4	33.2	34.4	6.9
All Untreated	17.2	27.6	27.6	24.1	3.4

Table 37. Implicit values needed to reach a breakeven point in Groups 1 and 4 where net present values were negative (Kalp and Howard 2020, forthcoming) using Equation 2.

		Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Standing Deadwood	**Mean Volume ($ft.^3$/ac.)**	996.1	1209.4	1073.2	1488.8	936.8
	Difference from Group 5 (untreated)	59.2	272.6	136.3	551.9	N/A
CWD	**Mean Volume ($ft.^3$/ac.)**	185.4	179	195.9	185.7	159.7
	Differences from Group 5 (untreated)	25.7	19.3	36.2	26	N/A
	Total Volume ($ft.^3$/ac.)	84.9	291.9	172.5	577.9	N/A
Implicit Value ($/ac./yr.)	**2%**	$0.096	N/A	N/A	$0.032	N/A
	4%	$0.087	N/A	N/A	$0.032	N/A
	6%	$0.084	N/A	N/A	$0.031	N/A

FIGURES

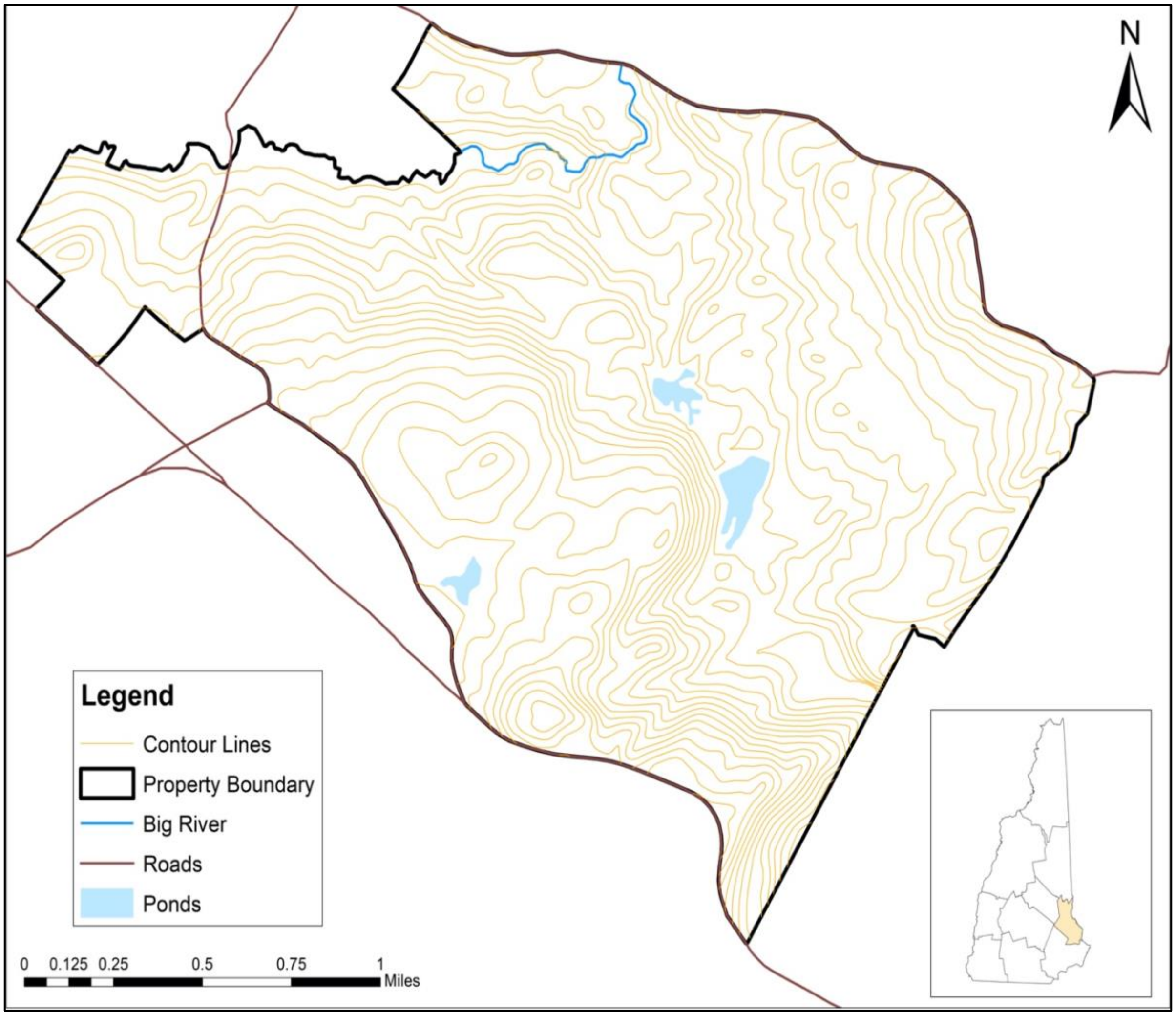


Figure 1. Feature map of study property. Blue Hills Foundation, Strafford County, New Hampshire.

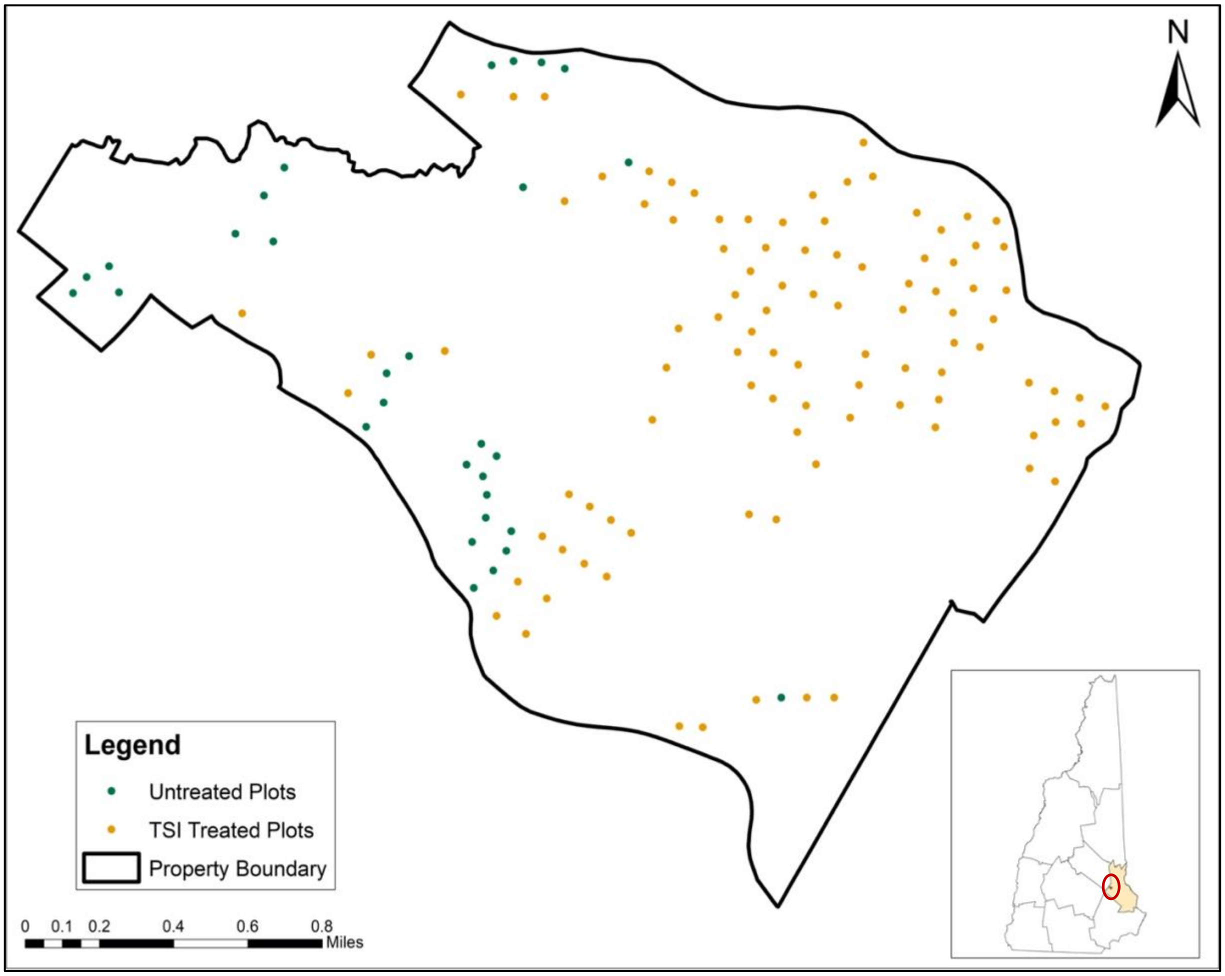


Figure 2. Locations of plots, Blue Hills Foundation, Strafford, NH.

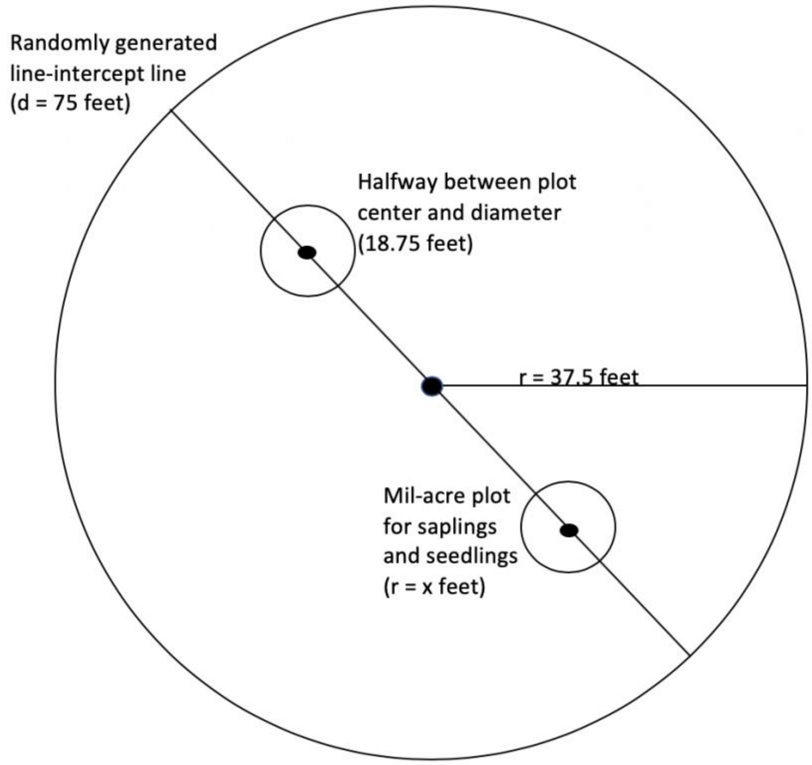
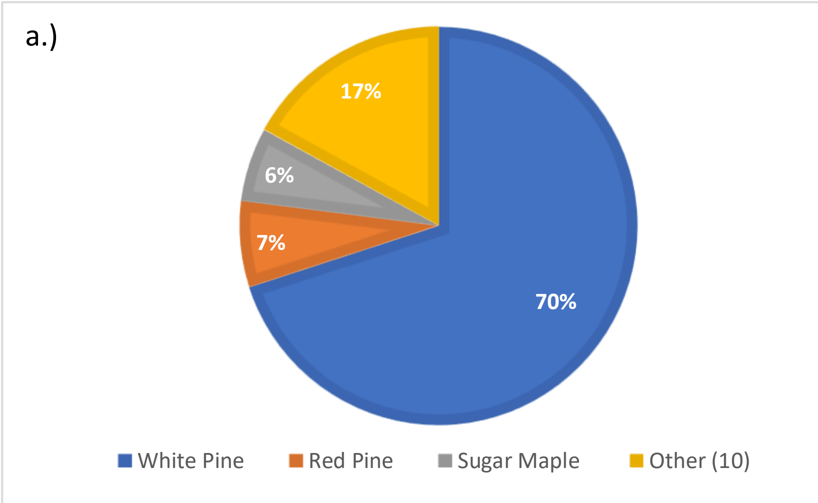
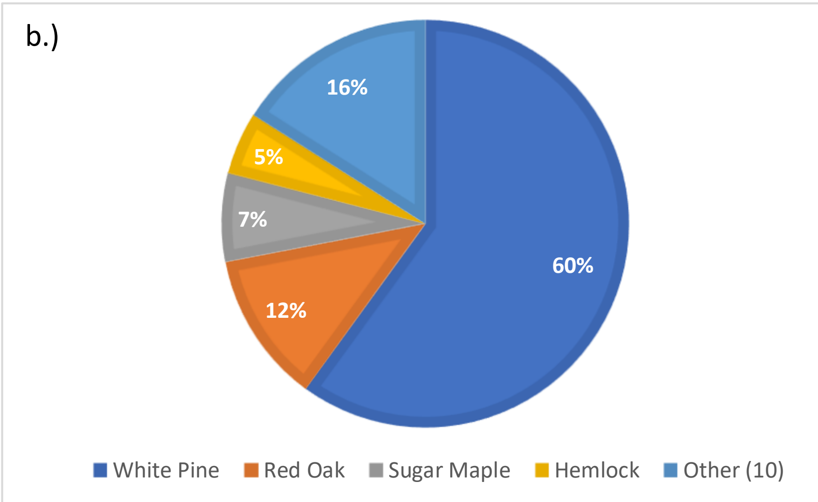
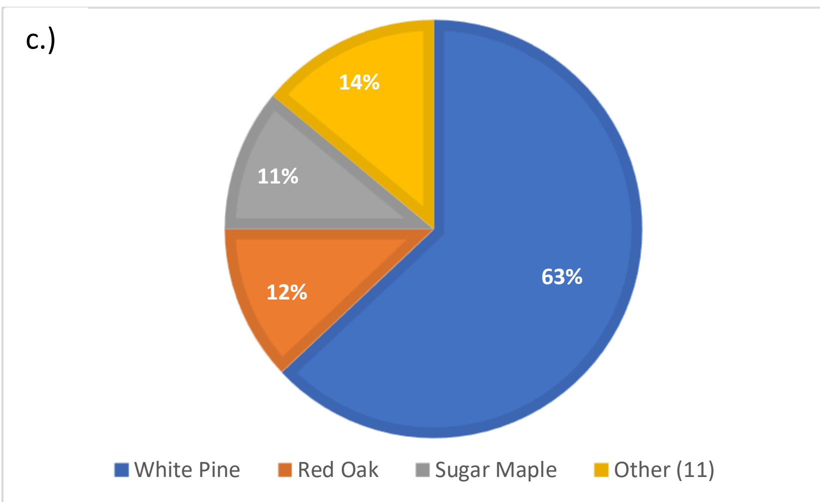
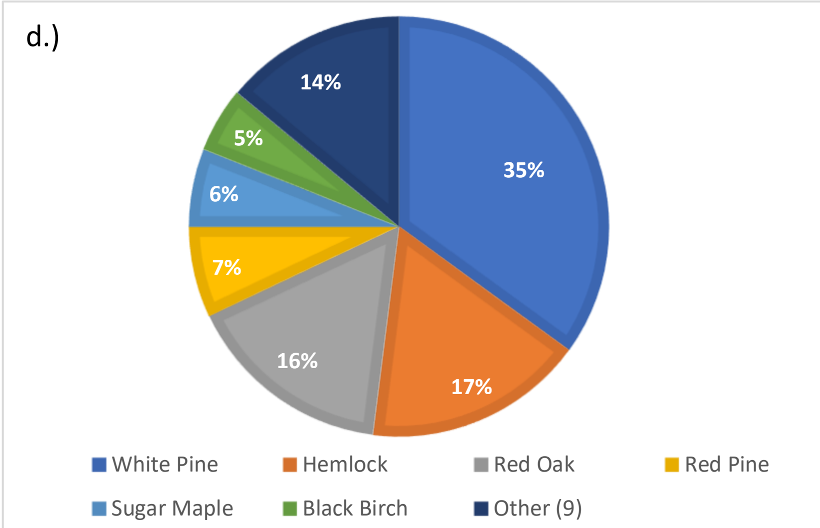


Figure 3. Diagram of plot layout including line-intercept for CWD evaluation.


a.)
17%
6%
7%
70%
White Pine
Red Pine
Sugar Maple
Other (10)


b.)
16%
5%
7%
12%
60%
White Pine
Red Oak
Sugar Maple
Hemlock
Other (10)


c.)
14%
11%
12%
63%
White Pine
Red Oak
Sugar Maple
Other (11)



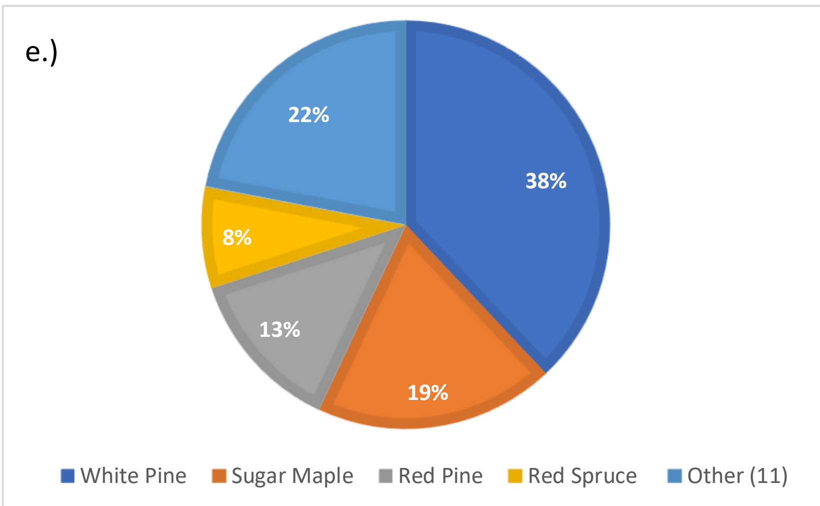


Figure 4. Basal area (ft.^{2}/ac.) percentage of major contributing species for a.) Group 1, b.) Group 2, c.) Group 3, d.) Group 4 and e.) Group 5 (all untreated). The value in parentheses after Other represents how many other species contribute to that percent of basal area in the groups.

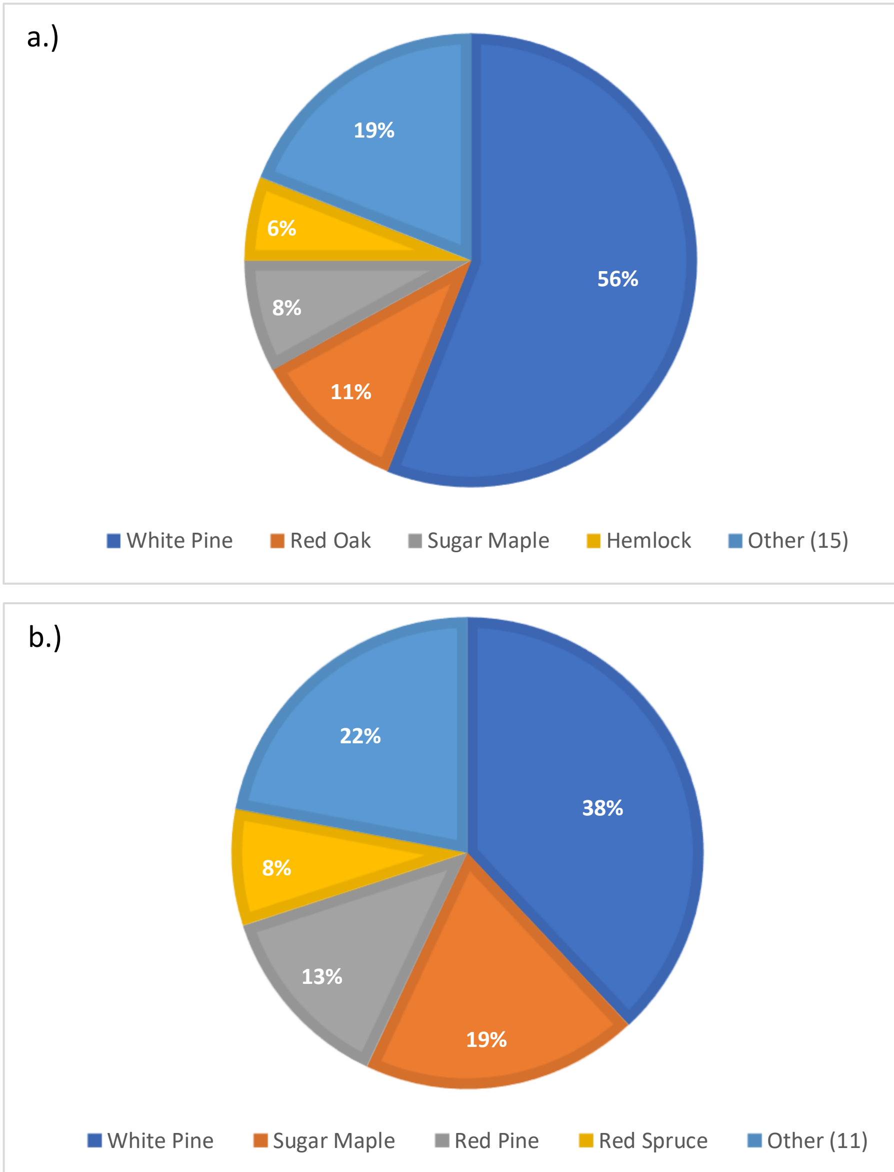


Figure 5. Basal area (ft.^{2}/ac.) percentage of major contributing species for a.) all TSI group and b.) all untreated group. The value in parentheses after Other represents how many other species contribute to that percent of basal area in the groups.

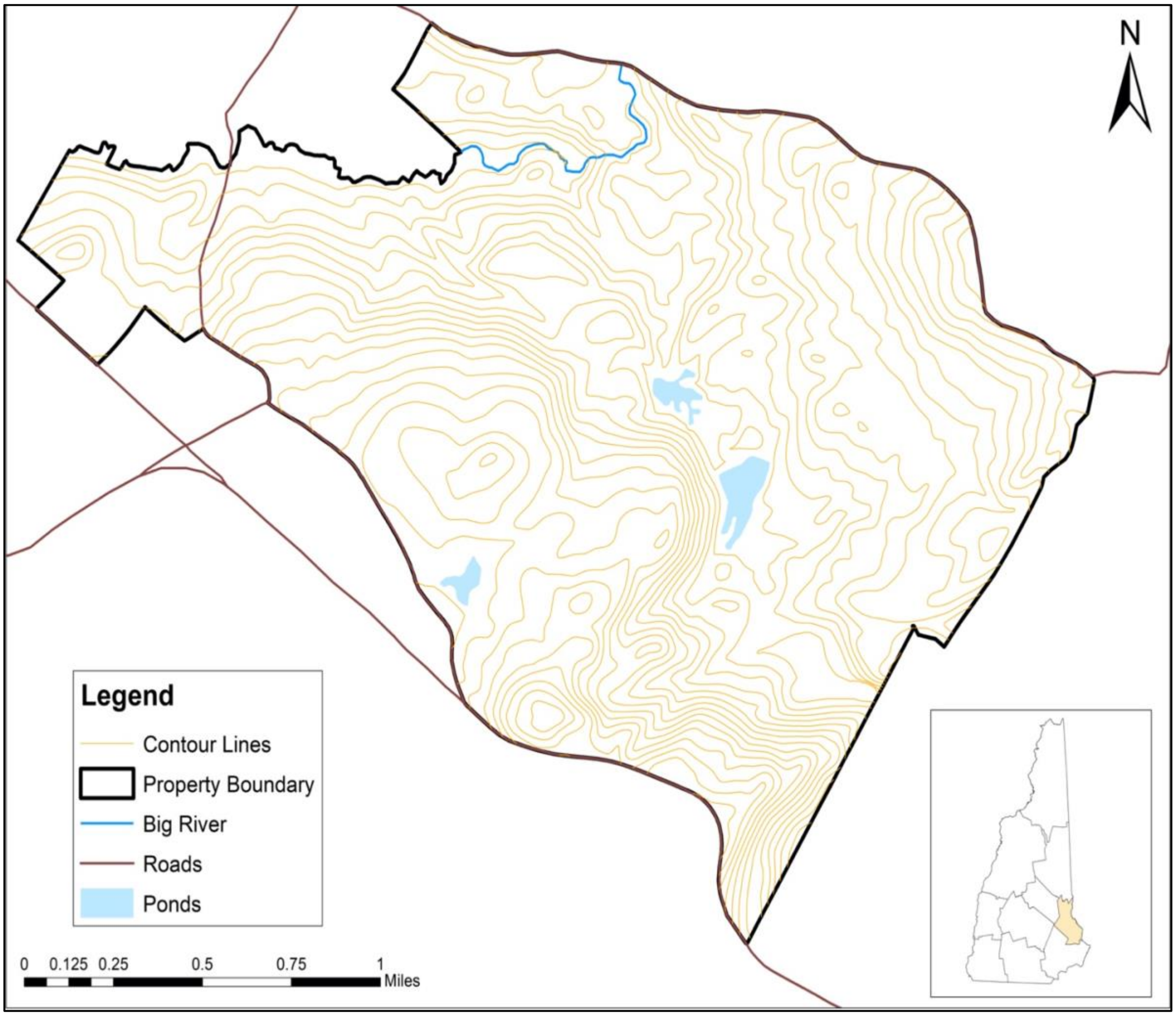


Figure 6. Feature map of study property. Blue Hills Foundation, Strafford County, New Hampshire.

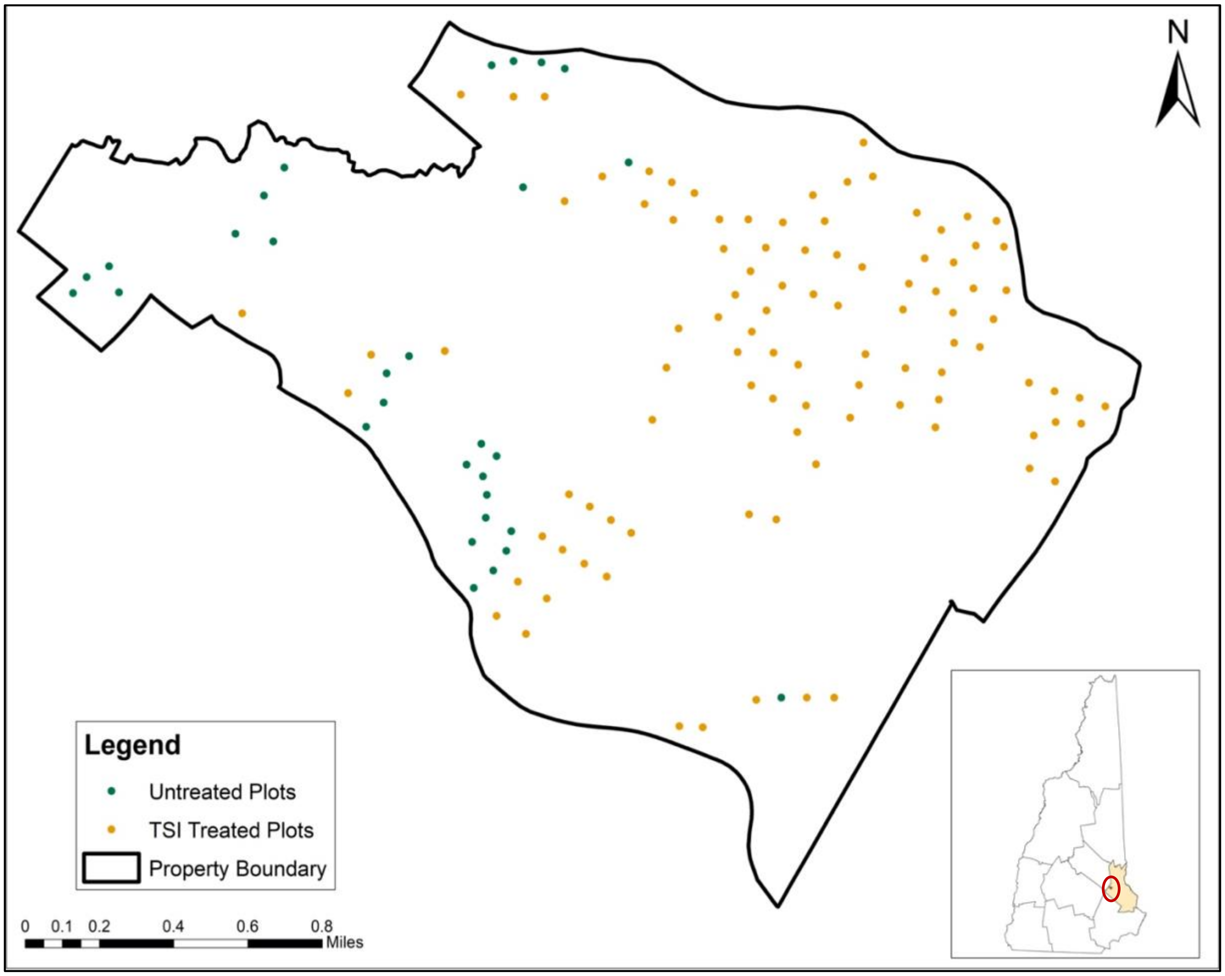


Figure 7. Locations of plots, Blue Hills Foundation, Strafford, NH.

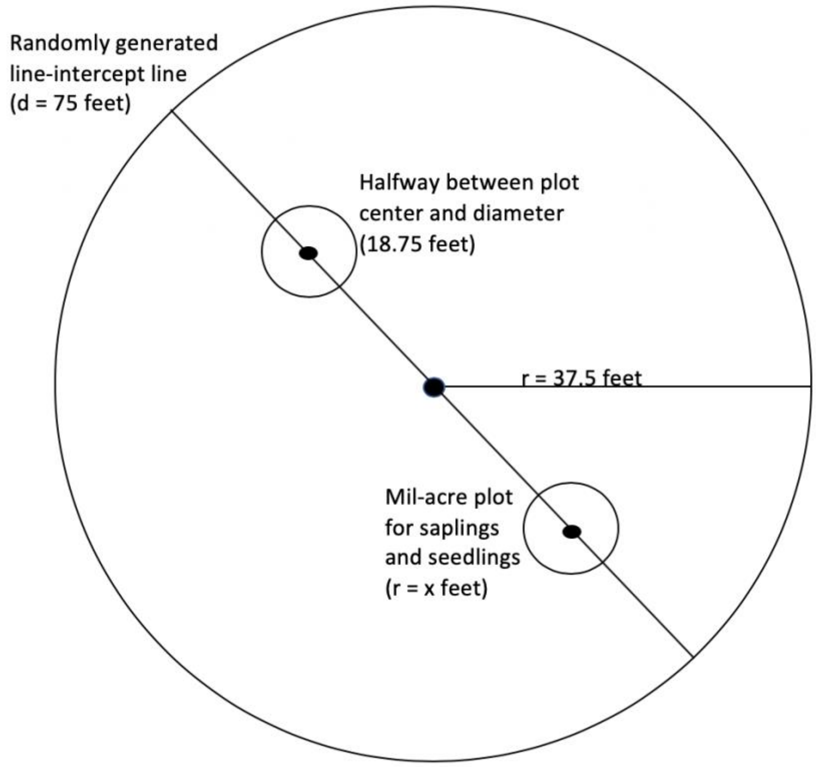
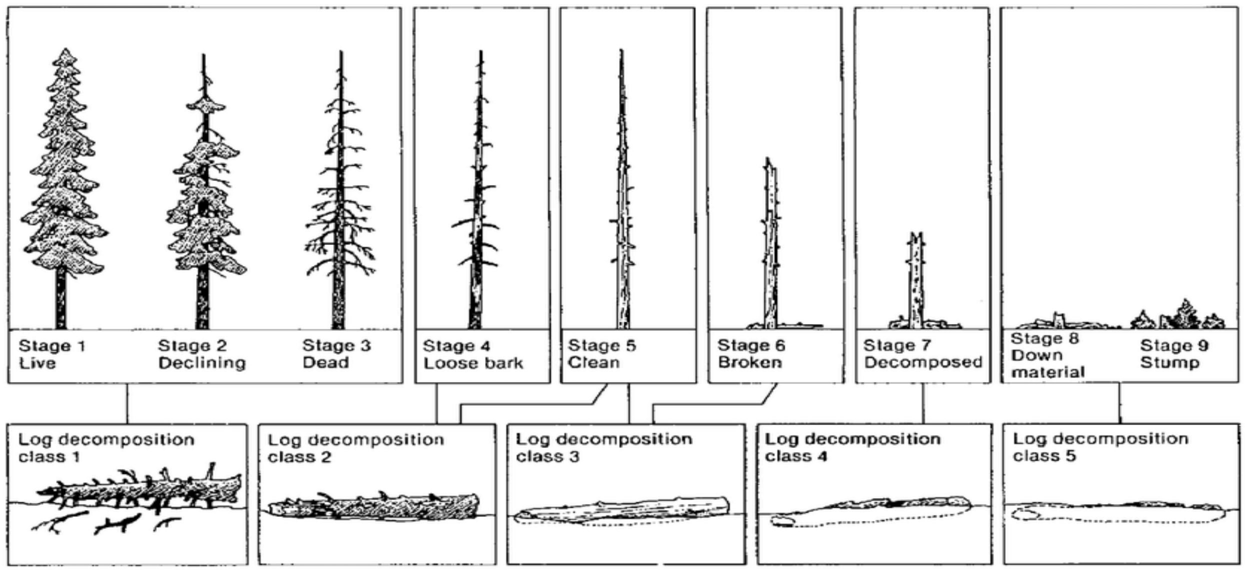


Figure 8. Diagram of plot layout including line-intercept for CWD evaluation and two mil-acre subplots for understory data.

Figure 9. Snag and coarse woody debris decay classes from Thomas et al. (1979).



APPENDIX

Table A1. Tree species values entered into NED-3 for 2019 timber value analysis (NHDRA 2019).

	Sawlogs ($/MBF)			Pulplogs ($/cord)
Species	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**
Hemlock	$60.00	$45.00	$30.00	$4.00
Red Pine	$55.00	$40.00	$25.00	$2.00
White Pine	$175.00	$137.50	$100.00	$2.00
Balsam Fir	$125.00	$102.50	$80.00	$0.10
Red Spruce	$125.00	$102.50	$80.00	$0.10
Black Spruce	$125.00	$102.50	$80.00	$0.10
Paper Birch	$100.00	$72.50	$45.00	$4.00
Yellow Birch	$200.00	$142.50	$85.00	$6.00
Red Oak	$400.00	$330.00	$260.00	$6.00
White Oak	$400.00	$330.00	$260.00	$6.00
White Ash	$200.00	$145.00	$90.00	$6.00
Red Maple	$150.00	$110.00	$70.00	$4.00
Sugar Maple	$265.00	$207.50	$150.00	$6.00
Black Cherry	$265.00	$207.50	$150.00	$6.00
American Beech	$100.00	$65.00	$30.00	$1.00
Gray Birch	$100.00	$65.00	$30.00	$1.00
Black Birch	$100.00	$65.00	$30.00	$1.00
Hophornbeam	$100.00	$65.00	$30.00	$1.00
Bigtooth Aspen	$100.00	$65.00	$30.00	$1.00

Table A2. Values used to calculate coefficient of variation to determine how many plots needed to be sampled for a 90% probability of achieving 10% error.

Mean Basal Area (BA) of all TSI Plots	**Mean Basal Area of all Untreated Plots**
13.23772233	23.24012943
Standard Deviation of BA of all TSI Plots	**Standard Deviation of BA of all Untreated Plots**
3.80591827	4.60238412
CV of BA of all TSI Plots	**CV of BA of all Untreated Plots**
0.287505522	0.293057857
# of TSI Plots Needed	**# of Untreated Plots Needed**
22.36784712	23.24012943
Actual # of TSI Plots Completed	**Actual # of Untreated Plots Completed**
97	30

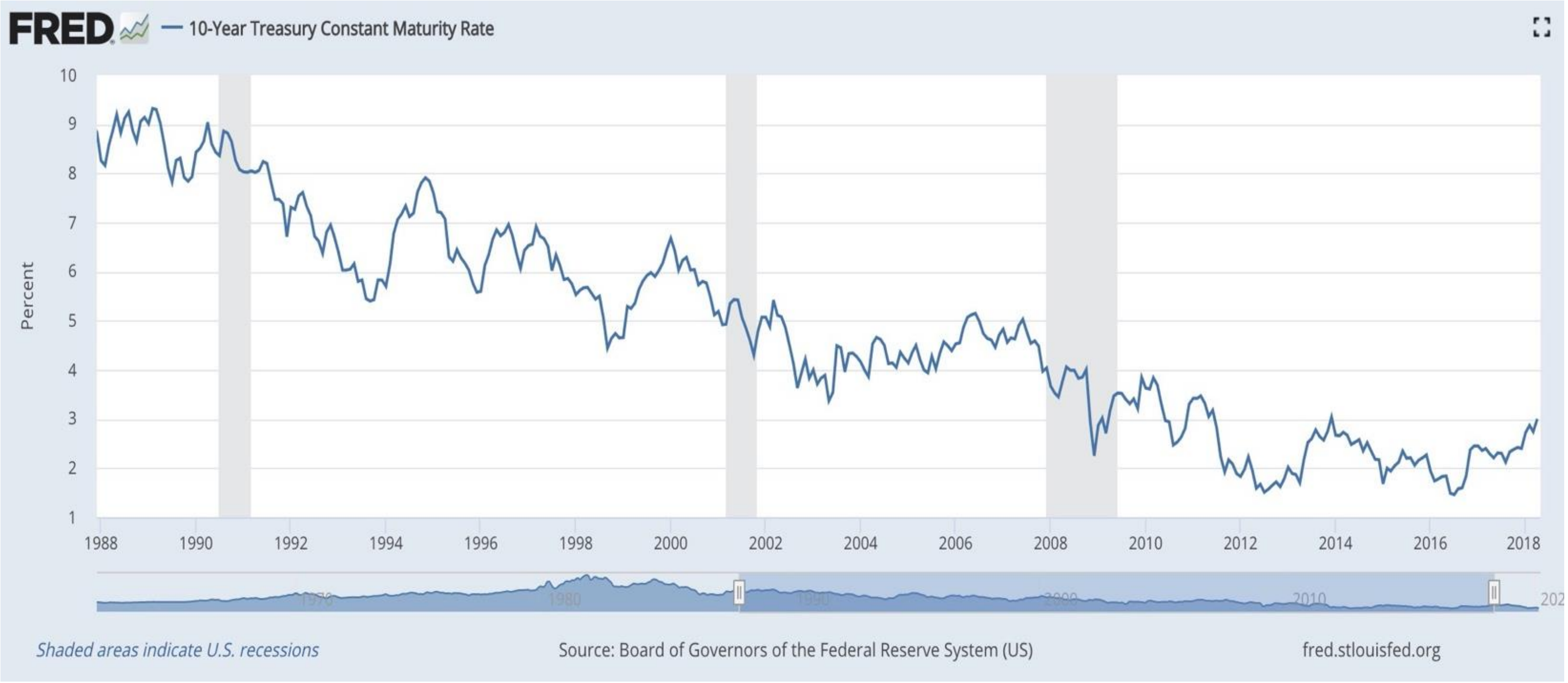


Figure A1. Interest rates from the Board of Governors of the Federal Reserve System (2019).